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Brain

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THE ADVANCEMENT OF LEARNING

BRAIN.

PART I., 1908.

Original Articles and Clinical Cases.

AMYOTONIA CONGENITA.

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AND

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Synonyms.—Myatonia congenita (Oppenheim); Kongenitale Muskelatonie (Tobler); Maladie d'Oppenheim (Baudouin); Atonische Zustände der kindlichen Muskelatur (Bing); Congenital Hypotonia or Amyoplasia (Carey Coombs); Myopathy, infantile type (Batten).

IN 1901 Oppenheim [17] first drew attention to a malady of early childhood characterised by such striking clinical peculiarities and so unlike any disease which had been previously described in its clinical aspect and progress that he felt justified in describing it as a new and separate clinical entity under the name of myatonia congenita. Since this time a number of cases have been reported, and all authorities who have written upon the subject have supported Oppenheim's claim that this disease constitutes a new and striking clinical type. The first case reported in this country was discovered by us at the National Hospital early in 1907.[1]

The patient was shown by us before the Neurological Society, and a lecture upon the subject was delivered by one of us at the National Hospital in the spring of 1907. Since then we have met with three other cases. In 1903 Dr. F. E. Batten [1] showed three patients before the Neurological Society of London which were undoubtedly cases of amyotonia congenita. He described them as cases of "Myopathy of an Infantile Type." We have included these cases in our list as they were certainly the first to which attention was drawn in this country. Our four cases have shown certain features to which attention has not hitherto been drawn, and the object of this paper is to point out these features, to call attention to Oppenheim's malady as a distinct and important clinical entity, and to put before the reader a complete account of all the cases which have been recorded up to the present time.

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[1] In a personal communication Dr. Carey Coombs tells one of us that his case was in manuscript for a year before it was published (June 15, 1907)

The essential diagnostic characters of Oppenheim's disease that will serve to distinguish it at once from all other diseases may be stated in a few words, which are here emphasized:—

"A condition of extreme flaccidity of the muscles associated with an entire loss of the deep reflexes, most marked at the time of birth and always showing a tendency to slow and progressive amelioration. There is great weakness but no absolute paralysis of any muscle. The limbs are most affected, the face is almost always exempt. The muscles are small and soft, but there is no local muscular wasting. Contractures are prone to occur in the course of time. The faradic excitability in the muscles is lowered and strong faradic stimuli are borne without complaint. No other symptoms indicative of lesions of the nervous system occur."

Under the name of congenital muscular atonia Sorgente [24] has described two cases occurring among the children of the same mother (*vide* p. 42). These cases seem to us to depart too widely from the type of Oppenheim's malady, which in all other reported cases has been so regular, to be justifiably included in this description in the present state of our knowledge. But since we have ourselves had the opportunity of observing a case of Sorgente's familial type, and since a complete pathological investigation was made by Dr. Batten, we shall here exclude these three cases from our general consideration of Oppenheim's disease, and we shall describe them in detail separately, leaving subsequent investigation to determine their position in relation to the usual type of congenital amyotonia Our reasons for excluding these cases are the following:—

(1) The malady was familial. In Sorgente's cases two children of the same mother were affected; in our case five children of the same mother were affected.

(2) The paralysis was complete.

(3) There was complete loss of electrical excitability in the affected muscles.

(4) All the cases ended fatally within a few weeks.

(5) None of the above features have occurred in any of the cases here included as cases of Oppenheim's disease.

Our best thanks are here expressed to Dr. Beevor for his permission to make use of two patients under his care in the National Hospital; to Dr. Whait, of Hampstead, for the early notes of the patient who had been under his care for several years, and for his kindness in affording us every facility to examine and photograph his patient; and to Professor Oppenheim, who was good enough to examine one of our patients and to give us the advantage of his valuable opinion and comments upon the case.

CAUSATION.

A careful search through the history of the recorded cases for any possible antecedents and factors in causal relation with this strange malady have thrown no light upon its etiology. Certain negative facts, however, are of considerable importance, especially in the distinction of this malady from other forms of paralysis occurring in the earliest years of childhood.

Age.—In nearly all cases the paralysis has been obvious at the time of birth or it has been noticed so few hours after birth as to make it certain that the condition has been pre-natal. This was so in eighteen out of twenty-five cases, but in four of the remaining cases it seems certain that the paralysis either appeared or became much aggravated many months after birth. These cases demand special consideration, for they form exceptions to one of the most characteristic features of this disease. In Schüller's case it is certain that the child was generally weak from birth, but it is also certain that, having learned to sit and stand at ten months of age, the child became much worse as regards weakness and atonia and lost the power of standing and sitting up. In Rosenberg's case the child seemed normal at birth: it learnt to sit up at seven months and the paralysis and flaccidity of the legs were not noticed by the parents till the child was eleven months old. In one of our cases the child seemed natural to its parents until it was nine months old, when weakness of the legs became rapidly manifest.

We are justified in agreeing with other authors that in some of these cases the condition became obvious just at the time when some attempt is usually made by parents to get a child upon its legs; that the condition was confined to the legs and lower trunk; and that these cases were not of a severe type. It is possible that in these three patients the condition was present at birth, and that it became more obvious when attempts were made to support the weight of the body upon the legs.

We are of opinion that several writers have carried this argument too far for the purpose of reducing exceptions in attempting to make clear a new clinical entity, and we are bound upon the present evidence to emphasize a post-natal as well as a pre-natal onset for Oppenheim's disease.

In three cases the condition came on rapidly and reached its maximum within a few days of the onset of an acute illness in a previously healthy child. In one of our cases (13) an attack of acute bronchitis was followed by "complete paralysis" within a week in a child of twelve months of age, who had been up to this time apparently quite healthy. In Leclerq's case a healthy child, aged seven weeks, was seized with broncho-pneumonia and became universally paralysed within a few days, and though slow improvement had gone on all the time, four years later the case was typically one of amyotonia congenita. In Comby's case (15) the amyotonia came on rapidly following an attack of diarrhœa at four weeks, and was almost universal in its extent and severe in degree, but four months later the upper extremities and trunk had completely recovered, but a typical condition of amyotonia still remained in the lower extremities. The history of these three cases hardly admits of the explanation that we are here dealing with the effect of an acute illness in bringing into evidence an amyotonic condition already present in minor degree, but it suggests strongly that an acute toxic process was the cause of the amyotonia.

In the three other post-natal cases—(12) (Collier and Wilson), (21) (Rosenberg), and (22) (Schüller)—the onset was slow and was not preceded by any sign of general ill-health. In one case the power of observation of the mother was so limited as to make it extremely likely that the amyotonia was present at the time of birth, but there is no evidence that this was so in the cases of Schüller and Rosenberg. It seems probable that these are cases of a congenitally installed disease with a slow post-natal development of symptoms which, having lasted for a certain term, gives place to a tendency to marked amelioration.

Sex.—There seems to be a greater incidence of the disease upon males. Of twenty-five cases fourteen were males and ten were females. In the remaining case the sex is not stated.

Heredity.—The cases of Sorgente's type being excluded there is no trace of any direct or indirect heredity nor of any familial tendency in this disease, nor has any neuropathic tendency been marked in relation with it.

In the search for the causal factors of any disease present in the child at the time of birth, attention first rests upon the condition of the maternal health during the period of gestation of the afflicted child. In amyotonia congenita, acute illness, toxæmia, mental distress, debilitating influences have not been conspicuous. The pregnancies seem to have been natural in every way and to have been passed without incident. In one case the mother is said to have been weakly during her pregnancy; in another case the mother was exposed to the strain, privation, and hurried journeys entailed by residence in South Africa during the war

In every case pregnancy continued to the full term and birth was natural. The children affected with this disease seem without exception to have been of good size and weight and of healthy general appearance at the time of birth. Miscarriages do not appear to have been prevalent from the family histories, nor is any unusual mortality to be found among the children. Signs of congenital syphilis and of rickets have not been met with in a single instance.

ONSET.

In a large majority of the cases the peculiar limpness and weakness of the muscles have been noticed so soon after birth as to make it absolutely certain that the condition was present during intra-uterine life. In two cases reported by Rosenberg and Cattaneo quickening was absent during the pregnancy, whereas these mothers had noticed quickening in all their other pregnancies. This suggests the possibility that the condition may date far back in intra-uterine life. The facts that in Rosenberg's case the lower extremities only were affected (a condition insufficient of itself to account for the absence of the movements), that quickening is notoriously an irregular phenomenon, and that in severe cases the fœtal movements have been felt quite vigorously up till the time of birth, are against this suggestion. In three cases the condition was noticed not long after birth, and these may well be congenital cases in which, either from a lack of observation on the part of the parents or from a less obvious degree of the disease, attention was not sooner drawn to the abnormal condition of the children.

In four cases, those of Rosenberg, Schüller, and Collier and Wilson (12) (13), the condition did not attract attention till the ages of eleven months, ten months, six months, and twelve months respectively. Previous writers have one and all made the attempt to drive these cases of late onset into the same clinical group in which symptoms are present at the time of birth. They argue lack of observation on the part of the parents, and that the disease, always present, becomes much more obvious when the child begins to sit up and attempts to stand; and further, in those cases where the condition has been noticed for the first time after acute illness, that the acute illness has had the effect of rendering a weakness already present much more apparent. While in one of our cases (12), in which the mother dated the onset at six months, her power of observation was so limited that she stated that the upper limbs were not affected, whereas they were most conspicuously affected; and it is quite likely that in this case the condition was present at birth, yet in the other cases it is quite certain that the children were normal for some time after birth and progressed in learning to stand and walk like other children and at a similar age. We must, then, recognize that the disease may arise in an apparently normal child at any period during the first year of life. The latest onset recorded is in one of our cases at twelve months. In three of the cases of post-natal onset the disease has immediately followed an acute illness, in two cases acute bronchitis, and in one case diarrhœa. Recognizing the post-natal onset of this disease in a minority of the cases, we consider that even in these cases we may be dealing with a disease that is congenitally installed.

CLINICAL ASPECT.

Distribution.—The incidence of the disease upon the musculature is peculiar and forms a highly characteristic feature, which serves at once to distinguish this malady from other diseases of childhood in which smallness and weakness of the muscles are associated with atonia and loss of the deep reflexes. The affection is always strictly symmetrical upon the two sides, it may be universal in distribution, but the muscles of mastication and deglutition seem always to have escaped. When the affection is general the several parts of the body are never equally affected: the lower extremities are most often and most deeply involved, next the upper extremities, then the trunk, and lastly the face. It must be clearly understood, however, that the distribution of the affection is not in terms of the long axis of the body—face least and lower extremities most—for in one case (11), in which the face, arms and legs were severely affected, the trunk was not involved; and again in Case 20 the trunk was normal where both upper and lower extremities were much affected.

In every case the lower extremities have been involved, but in several cases (11 and 12 and others) the upper extremities have been much more severely affected than the lower extremities.

In the twenty-five cases the distribution in the several parts of the body has been as follows:—

	Involved.	Normal.	Not noted.
Face	3	20	2
Trunk	22	3	—
Upper extremities	20	5	—
Lower extremities	25	—	—

In the face the orbiculares palpebrarum and the retractor muscles of the angle of the mouth are the muscles chiefly involved, inability to close the eyes completely, epiphora and a blank expression of face resulting. The orbicularis oris seems never to be involved, and the same applies also to the muscles of mastication and of the tongue. All the infants with facial affection have been able to suck strongly and to swallow well. The pouting lips and furrows indicating local muscular wasting which characterize the myopathic face are never seen. The ocular muscles seem never to be affected.

In the limbs the amyotonia may be distributed equally upon both proximal and distal parts, but this is unusual. It has been stated by most of the previous writers upon this subject that the proximal muscles are always more severely affected, but it seems to us certain that this conclusion has been arrived at from the obvious disadvantage at which the proximal muscles act against gravity upon the limbs as long levers. Our experience is that in some of the cases the proximal muscles are more severely affected, as shown by their smaller size and softer feel, by their electrical reactions, and by their power of action in the most favourable position of the limb. In other cases the reverse is true, the peripheral muscles being much more affected than the proximal muscles. We are inclined to think that the major affection of the peripheral muscles is the more common event, for the peculiarities of growth attributable to the lack of the tonic traction of the muscles are only apparent in the hands and feet.

The proximal and peripheral major distribution of the affection does not alternate in the same subject; in a given case the major incidence is either all proximal or all peripheral.

It cannot be too strongly insisted that in amyotonia there is no local muscular atrophy comparable to the local atrophy which is characteristic of all cases belonging to the group of the myopathies. The smallness of the proximal muscles of the upper extremity, for example, in a given case of amyotonia involves all the muscles from the scapulo- and humero-thoracic muscles to the elbow: all these muscles are equally small and equally weak, and the conspicuous local atrophy of the lower part of the pectoralis major, one of the earliest and most constant signs of myopathy, is never present.

The distribution of the contractures is peculiar. They have only been met with in the lower extremities and they do not correspond either in position or in degree with the severity of the amyotonia. In Cases 11 and 12, for example, contractures were very marked in the lower extremities, whereas the amyotonia was more marked in the upper extremities, and in the first of these cases contractures were present so severe as to necessitate bilateral tarsectomy, though the legs had recovered to such an extent as to permit of walking and the knee-jerks had returned.

MUSCULATURE.

The condition of the affected muscles is one of complete tonelessness with the preservation of some degree of voluntary power, though in severe cases this voluntary power may be insufficient in a proximal muscle to raise the limb against gravity. This condition has led to descriptions of complete paralysis in this disease, but careful investigation has shown that, however complete the apparent paralysis may be, yet every muscle when put into a favourable position as regards work involved contracts voluntarily. A similar condition of complete apparent flaccid paralysis in muscles which will contract voluntarily is seen in cases of chorea mollis. With the extreme limpness of the muscles is associated also considerable relaxation of the ligaments, and the most fantastic positions of the limbs and trunk may be assumed. One mother described the condition of flaccidity of her child a fortnight after birth as follows: "By whatever part of the body I held him up, all the rest of him hung down like so many pieces of yarn." The extraordinary positions into which the limbs can be placed without causing pain have in several instances first drawn the attention of the parents to something being wrong with the children. In most of the cases inability to hold the head up and to sit up have been conspicuous, and when placed in the sitting position the body becomes bunched up just as gravity and the bony parts of the body dictate. It is remarkable that no spinal deformity has occurred from this state of instability of the trunk.

The relaxation of muscles and ligaments allows of the most remarkable over-extension of the joints, and leads to a highly characteristic flail-like condition of the joints when shaken. For example, if the upper extremity of one of our cases (13) was held out at right angles to the body (the observer's hand grasping the upper arm below the insertion of the deltoid), the elbow-joint formed an angle backwards of about 145 degrees, and if the arm thus held was gently shaken the bony surfaces of the elbow-joint knocked together audibly, and if the forearm was held the wrist and fingers could be shaken like a many-tailed whip. The wrist and fingers can often be over-extended so as to come into complete contact with the back of the forearm. A capacity for extreme hyper-extension of the ankle-joint has been a marked feature of many of the cases, and in several, including one of ours, the position which the foot assumed at rest was with the whole length of the dorsum of the foot lying along the front of the tibia. In this place may be mentioned also the tendency for the hands to be unduly long and narrow and for the feet to be most strikingly long, narrow, and pad-like: this latter feature is highly characteristic of the malady.

The muscles are small, and impart a peculiar soft velvety sensation to the touch, quite different to the feel of normal muscles on the one hand or to that of myopathic muscles on the other hand. The hard patches that are so often to be felt in the muscles of myopathy, even when there is no pseudo-hypertrophy, are never present.

Very striking and peculiar to amyotonia is the impossibility of distinguishing by the touch between the skin, the subcutaneous tissue and the underlying muscle. One can make no separation between these structures, and from the skin down to the bone there seems to be but one soft homogeneous substance.

There is no local wasting of the muscles, although, as has been already pointed out, the relatively smaller size of the proximal muscles of a limb, compared with the size of the peripheral muscles, may be conspicuous in a limb where the proximal muscles show a much higher degree of amyotonia; and conversely, where the amyotonia is more marked in the muscles of the periphery, these may be conspicuously smaller than the proximal muscles. Smallness in size of one individual muscle, or of part of a muscle, such as is so commonly met with in cases of myopathy, never occurs in amyotonia.

The general outline of the limbs, as determined by the muscles, is not altered in amyotonia, though, on account of the general smallness of the muscles, the contour of the limbs is less distinct than in the normal subject. We wish to emphasize this fact in this place as important in the distinction of amyotonia from myopathies, for in the latter class of diseases the contour of the limbs becomes much altered from the normal by the local atrophy of individual muscles, and sometimes by the hypertrophy of others.

Fibrillation has not been observed in the affected muscles, and the effect of local mechanical stimulation is not conspicuous.

It seems that those muscles that are more closely concerned in the vital processes—muscles that are employed in sucking, swallowing and in respiration—tend to escape in amyotonia, for in all the cases in which the face has been affected it has been especially noted by the authors that sucking, mastication and swallowing were well performed, and in none of the cases has it been noted that the diaphragm or the intercostal muscles were weak. From the fatality of bronchial affections among the cases it is probable that the muscles of respiration are in some degree at fault.

The loss of power in the affected muscles varies from slight weakness, showing itself only after exertion, to complete inability to move a limb against gravity, and each degree between these extremes may be seen in the muscles of the same patient in whom the degree of amyotonia varies in different parts of the body. As a rule the loss of effective power is great. Only one of the twenty-five recorded cases—apart from Carey Coombs' case—is able to stand and walk feebly, and this result has been attained after six years careful treatment. Only a few of the patients have been able to sit up, and in the cases where the upper extremities have been affected but few have been able to make any effective use of the hands. Our cases, however, show that there is the most surprising volitional control in these useless and flaccid limbs. Provided that too much power is not required for the act or to overcome gravity, we have found that the most complicated movements can be performed quickly and with a fair degree of precision.

Attitude.—The inability to hold the head erect is conspicuous in severe cases: the head rolls round anywhere upon the circle which its attachments limit. If the little patient be placed in the sitting position the body bunches up generally when the trunk is affected. The usual attitude for the lower extremities at rest is that of slight flexion and marked external rotation at the hips; flexion at the knees—the calves being in contact with the hamstrings—and extreme dorsiflexion at the ankle, the plantar aspect of the long pad-like foot being turned upwards.

Contractures have been present in all our own cases. In two cases they were of slight degree and in the other two cases of severe degree. They have been reported in eight of the twenty-five cases, and it seems probable to us that they have been overlooked in some of the others, though Professor Oppenheim told us that ours were the only cases that he had seen with contractures. These contractures have been noted only as occurring in the lower extremity, and the most usual form is a flexor contracture at hip and knee of moderate degree. In three cases contracture of the calf muscles is reported, and in one of these there was also contracture at the hip and knee. In our case (11) the contracture of the calf muscles had produced so much deformity of the feet that a double tarsectomy was necessary to bring the feet to a right angle.

Facial affection.—In only one case among the twenty-five reported cases has there been conspicuous affection of the face (11) (Collier and Wilson). In Carey Coombs' case it is described as possibly weak, and in Tobler's case as slightly weak. In our case there was extreme weakness of the upper facial muscles; the child never frowned when crying and never wrinkled the brows. With his strongest effort to screw up his eyes ⅛ in. of the sclerotic was still visible, and there was no sign of corrugation of the orbicularis palpebrarum. The weakness of the tensor tarsi was shown by the readiness with which epiphora occurred. The face had a blank and stupid expression, which was increased by his inability to close the mouth, due to a deformity of the lower jaw which brought the back teeth in contact while the incisors were still 1 in. apart. Retractor and levator movements at the angle of the mouth were never seen even when he was crying. The orbicularis oris, however, was powerful; his lips did not hang away from his teeth, and his articulation was good. Though this facial affection had been present since birth, and had apparently not improved, yet there were none of the signs of wasting of the facial musculature that characterize the myopathic face.

Electrical reactions.—All the muscles respond to the faradic current, but a very strong current is necessary to produce a comparatively small contraction. To galvanism the muscles usually contract well and briskly; there is no slow contraction and the polar reactions are normal. A tardy response to faradism with more or less normal galvanic reaction is so characteristic of amyotonia, and so infrequent in other diseases in childhood, as almost to deserve the name "amyotonic reaction." This peculiar reaction seems to be present in some degree in all the muscles of the amyotonic patient, but it is most marked in those muscles which are most affected. A remarkable peculiarity, possibly connected with the muscular affection, is the ease with which these little patients bear the strongest faradic stimuli. They are quite unperturbed at a strength of current that is unbearable to the ordinary person.

General Nerve Signs.

There are no signs of lack of cerebral development or of mental deterioration. Several of the children have been of precocious intelligence. No fits or other cerebral symptoms have occurred among any of the cases.

The special senses have been normal in all the reported cases.

The cranial nerves have been found normal in all cases. Strabismus has not been noticed, and the ocular muscles have been free from affection in all the cases.

Sensibility seems to be normal, and the only question is as to whether there is any defect of pain sensibility. The extraordinary indifference of these children to strong faradism has already been emphasized, and two of our patients seemed to take little or no notice of an ordinary pin-prick upon the affected limbs, though they objected strongly to severe pricks. In no case, however, has definite pain-loss been demonstrated.

The sphincters are never affected.

The superficial reflexes are always natural.

The deep reflexes are invariably lost in the regions where the amyotonia is marked. It seems highly probable that the deep reflexes are always absent in the first place, and that with improvement in condition of the muscles the deep reflex returns. Out of the twenty-five cases the knee-jerk was absent in twenty-two cases. In our case (11) the knee-jerk appeared after five years absence under constant observation, and when the patient had so far improved as to begin to walk. In Berti's case (6) the knee-jerk was present in a patient who had been regularly improving for five years. In Carey Coombs' case the knee-jerk was present in a slight case where the legs were recovering.

The wrist- and elbow-jerks were present in four cases, absent in fifteen cases, and not recorded in six cases. Of the four cases in which these reflexes were present, in one case (13) they returned after nine months treatment, great improvement in the upper limbs having occurred. In Comby's case (15) they returned under observation with rapid improvement. In Rosenberg's case the arms were not affected, and in Spiller's case the wording of the note leaves the reader in doubt as to whether these reflexes were present or not; probably they were absent.

The general health and vitality of the subjects of amyotonia seem to be good. We have been unable to detect any abnormality in the thoracic or abdominal viscera, and the same result has been arrived at by all other writers upon the subject.

COURSE.

The evidence of all writers upon this subject is in unison: that all cases of amyotonia tend to spontaneous improvement, and that this improvement occurs more rapidly under appropriate treatment. In no case has the least tendency to exacerbation of the disease been observed. But the improvement is very slow; in fact so slow is it in most cases that although the first case was published seven years ago we are as yet unable to say whether complete recovery ever takes place; and from a general consideration of all the cases it seems probable that improvement never reaches the stage of complete recovery. Professor Oppenheim tells us that though he has had several cases under his observation for years which have all improved markedly, yet at present they are all far from complete recovery. The most rapid example of recovery is Comby's case (15), in which the arms and trunk rapidly and completely recovered, but improvement in the legs was slow. The most complete case of recovery after a severe affection is our case (11), in which, after seven years of careful treatment, the child has learnt to walk and can now use his hands for most purposes; but here, too, recovery is far from being complete.

The disease seems to have no tendency of itself to shorten life, but the weakness of the trunk muscles decreases the resistance to [illegible] affections and increases their fatality. The bedridden [illegible] the more severe forms of the malady entail is [illegible] maladies, and death may thus result indirect [illegible]

When, as in [illegible] amyo [illegible] the d [illegible] weakness without complete paralysis and the loss of the deep reflexes—be borne in mind. There are, perhaps, only two classes of cases which bear a superficial resemblance to amyotonia, in that they may present conspicuous flaccid paralysis with loss of the deep reflexes immediately or soon after birth. The first group comprises those cases of obstetrical paralysis in which a severe injury to the spinal cord has occurred in the course of parturition. The injury is usually due to a fracture dislocation of the vertebral column in the lower cervical region, and it may, by causing a total physiological transverse lesion, produce a condition of flaccid paralysis with loss of the deep reflexes. But in such cases the paralysis below the lesion is complete and there is complete loss of sensibility, readily elicited even in the youngest infants by testing the surface of the body from below upwards with a painful stimulus; directly the line separating the non-sentient from the sentient part of the body is crossed the infant at once reacts to the painful stimulus. In such cases there is usually present some local atrophic paralysis of the arm musculature from injury either to the cervical enlargement or to the lower cervical roots.

The second group of cases which needs to be sharply distinguished from amyotonia is that of infantile acute spinal muscular atrophy of familial type. A case of this nature, in which several children of the same mother were affected, was observed by one of us throughout its clinical course, and was published by Dr. Beevor [3], with a full pathological report by Dr. Batten, the details of which are here appended. Sorgente has published two similar cases, the children of one mother, under the name of congenital muscular atonia. These cases certainly form a peculiar and striking clinical type of their own, and have in our opinion no connection with amyotonia congenita for the following reasons: all the described cases have been familial; the disease is not [illegible] at the time of birth, but appears somewhat acutely after birth [illegible] from a few weeks to several months. There is com- [illegible] the muscles with complete loss of faradic excita- [illegible] of sensibility to all forms of stimulation in [illegible] have ended fatally within a short [illegible]anges are found in the cells [illegible] will at once serve to [illegible] the completeness [illegible]plete birth, but becomes noticeable little by little as the child reaches that age when it is expected to sit up, crawl about, or attempt to stand, the disease must be distinguished from other causes of weakness in the limbs of slow onset occurring at that age. The peculiar flaccidity, and especially the absence of the deep reflexes, will serve at once to distinguish amyotonia from all such conditions. Conditions of rickety weakness of the limbs are never associated with loss of the deep reflexes unless some lesion other than the rickety state is present. The rare cases in which amyotonia follows rapidly upon an acute illness must be distinguished from anterior polio-myelitis on the one hand and from diphtherial palsy on the other hand. It may be pointed out that so far as the records go at present amyotonia has only followed upon acute bronchial disease. The strict symmetry of amyotonia upon the two sides, the absence of local muscular atrophy, the absence of any complete paralysis and the absence of the rapid narrowing down of the extent of the regions affected which follows an attack of infantile paralysis are points which should prevent the possibility of any confusion between the two diseases. Diphtherial palsy is exceedingly rare during the first year of life, which is the usual period of incidence of amyotonia. The absence of the deep reflexes, and to a certain extent the flaccidity of amyotonia, might be simulated by diphtherial palsy; but the presence of nasal regurgitation and of cardiac debility, and the history and course of the latter malady, should render impossible the making of any mistake between two maladies, which, while presenting a superficial resemblance in their clinical aspects, are essentially dissimilar.

There is, then, little difficulty in the recognition of this malady and in its separation from any other type of paralysis occurring in early infancy; but a question of great importance, and one that must be discussed at length, is whether this disease is to be considered as a variety belonging to the group of the myopathies or whether it is a clinical and pathological entity entirely separate from the myopathies. Previous writers upon the subject of amyotonia have for the most considered the myopathies in this connection only from a point of view of differential diagnosis, and have dismissed myopathy briefly as being clinically unlike amyotonia, and as a condition that was most unlikely to be confused in diagnosis with amyotonia. Dr. Batten, however, published his cases under the name of "Myopathy of an Infantile Type," and on the several occasions upon which we have shown our cases before the Neurological Section of the Royal Society of Medicine it has been argued against us that these cases should be described as a subgroup of the myopathies, and that we are not justified in following our predecessors who have written upon this subject in separating these cases as a distinct group apart from the myopathies under the title of "amyotonia congenita." In the discussion which occurred when these cases were exhibited it was pointed out that in one of our cases (12) certain of the humero-thoracic muscles were very small, and that this feature, associated with the marked contractures in the lower extremities, placed this case close to a common type of myopathy, and further that in our case (11) the facial weakness was identical with that seen in the Landouzy-Dejerine type of myopathy, and that these two cases showed transition from the type of amyotonia to the type of myopathy. And further it was argued that the amount of improvement that was obtainable in cases of amyotonia was slight, that the tendency to progressive improvement that we have emphasized was somewhat of a false description, and that many of the cases had not improved more than do some cases of myopathy under careful treatment, the course of the two diseases being much in the same line.

Before proceeding to the discussion of this question we must in fairness state that so far as the pathological evidence derived from the two cases which have been examined goes, it is quite compatible with a condition of myopathy, though the results in the two cases were widely at variance one with another.

We hold, however, that the group of cases which has been brought together under the name of amyotonia congenita is clinically quite distinct and has not as yet been proved to be associated with the myopathies. We base our opinion upon the following facts:—

(1) The myopathies are conspicuously familial diseases, whereas no familial tendency has been recorded in amyotonia.

(2) The several types of myopathies often show familial relationship one with another, whereas no case of amyotonia has been reported in a myopathic family.

(3) A large majority of the cases of amyotonia are congenital, the condition being obvious at birth; in a minority of the cases the amyotonia has appeared acutely and has reached its most severe degree in a few days. In none of its several types is myopathy apparent at birth, nor does it ever appear acutely and reach a maximum in a few days.

(4) The characteristic muscular flaccidity of amyotonia is not present in myopathy.

(5) The local muscular wasting that is a marked feature of myopathy is not present in amyotonia.

freedom of movement that is so essential to improvement. Splints, when used to reduce contractures, should be applied only at night.

PATHOLOGY.

The pathological changes which underlie the condition of amyotonia congenita have not been subjected to such investigation as will allow of an unequivocal statement as to their nature. Up to the present time three autopsies have been made and the results published in two of the cases only, the recent case of Variot and Devillers [27] being as yet recorded only upon the clinical side. The earlier authors, in default of any pathological results, theorized somewhat widely as to the nature of the disease, but it is only quite recently that we have had anatomical data with which to compare these theories. The first pathological account was published by Spiller [25] early in 1907, and later in that year a more complete anatomical examination of one case was made by Baudouin [2]. Marfan, at a meeting of the Société de Pédiatrie in Paris, in October, 1907, mentions that a complete pathological examination had been made upon a case of his, but in a personal communication he informs us that he referred to Baudouin's case, which was in his clinique.

Bing [7] removed and examined some muscle from his case, but he does not state from which region the muscle was removed.

The following is an abstract from Spiller's examination, containing all the important points:—

"The hypotonicity of the muscles twenty hours after death was as great as during life, and the absence of *post-mortem* rigidity was most striking. On cutting into the right calf the fat was found to be 6 mm. in thickness, there was very little muscle, and this appeared paler than normal. Hardly any perceptible muscle could be found in the sole of the left foot, and the tissue removed from this region consisted of fat with a very little muscle. A piece of the triceps brachialis was removed from the left side; this muscle was paler than normal and the overlying fat was 3 mm. in thickness. Muscles from the sole of the left foot, from the back of the trunk, and from the left calf had a hyaloid appearance, and those from the sole of the foot were striking on account of the large amount of fatty connective tissue and on account of the considerable increase in the nuclei of this connective tissue. The muscle fibres were small, and those from the sole of the left foot and from the left calf were much smaller than those from the back of the trunk. It is to be remembered in this connection that the child had more power in the muscles of the back than in those of the lower limbs. The transverse striations of the muscle fibres were well preserved, but the longitudinal striations were not so distinct. The nerve fibres within the muscle from the sole of the foot appeared to be normal.

"The spinal cord and brain were found to be well developed, and the anterior and posterior roots were normal. The nerve cells of the anterior horns of the cervical and lumbar regions, examined by the thionin method, were found to be normal. The spinal meninges were normal. The pyramidal tracts in the cervical and lumbar regions were not degenerated, and sections of these regions, examined by the Marchi method, showed no sign of degeneration. The nerve cells of the paracentral lobules, examined by the thionin stain, seemed to be normal, but Betz's cells were not numerous in the sections examined. This did not indicate that these cells had degenerated. A nerve trunk from the upper part of the right upper limb, examined by Weigert's method and by acid-fuchsin with hæmalum, was normal. The internal popliteal nerve and a nerve from the upper part of the right upper limb, teased in a 1 per cent. solution of osmic acid, were normal."

The all-important results of Spiller's examination are: (1) The absence of any appreciable abnormality in the peripheral and central parts of the nervous system; and (2) the intensity of the muscular regression in the affected regions. Definite lesions of the thymus gland and of the hæmolymphatic system were present.

The following is an abstract from Baudouin's examination, containing all the important points:—

"The autopsy was made twenty-four hours after death, the subarachnoid space having been injected with a solution of formalin two hours after death. The muscles were sunk in fat and their colour was very pale, the subcutaneous layer being 1 cm. thick. There was difficulty in isolating the rectus femoris from the fatty sheath around it. The muscles presented extensive pathological changes, the most obvious lesion being an intense sclerosis. There were numerous thick strands of connective tissue in the muscle, the vessels of which were somewhat thickened and were surrounded by a ring of deeply staining young cells, in which there was a fair proportion of eosinophile myelocytes. Some of the muscle fibres were swollen and hypertrophied, their diameters being as much as 100 μ. Surrounding these were collections of quite small fibres averaging not more than 6 μ to 8 μ; these were specially noticeable in the triceps and ilio-psoas. The nuclei of the sarcoplasm were increased in number and sometimes locally invaded the interior of the fibres. Transverse sections revealed many muscle spindles. In longitudinal sections the transverse striation was conspicuous by its absence, while the longitudinal striation was very well marked."

In Baudouin's opinion the lesions were those of muscular regression such as are seen in the myopathies.

"Examined by Nissl's method, the cortex of the Rolandic convolutions was normal. The oculo-motor nuclei and the motor fifth nuclei were normal upon both sides, but some of the cells of the sixth and of the twelfth nuclei were in a state of chromatolysis.

"No abnormality was discovered in the spinal cord by the methods of Pal and Marchi.

"Examined by Nissl's method, the anterior horn cells of the spinal cord were diminished in volume, compared with the cells of Clarke's column at the same level; for example, at the lower part of the eighth cervical segment. As is usual, those of the internal group were smallest, but in the external group, where the cells were larger, their diameter was not more than 25 μ, and they were fewer in number. The blood-vessels were normal, and there was no trace of neuronophagia. The same features were observed throughout the spinal cord.

"A section of the anterior and posterior third left lumbar roots showed that the former (anterior) roots were at least four or five times less than the latter (posterior) roots. Now in the normal subject the anterior root at this level is about half the size of the posterior root. In addition, the posterior root took the stain much more deeply than did the anterior root. In the anterior root also the sheaths were more widely spaced and were separated by amorphous tissue.

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"Sections of the sciatic nerve stained by Weigert's method showed that the nerve was not normally coloured, the myelin sheaths being scattered and unequal in the different bundles. Sections stained with hæmatein eosin showed the axis cylinders rose coloured, and these seemed to cover the field uniformly, the conclusion being that many of the axis cylinders were not yet myelinated. There was, in addition, a slight sclerosis, the nuclei of the sheath of Schwann being slightly increased in numbers.

"The condition of the nerves, therefore, was a delay in myelinization—an arrest of development—but there was no neuritis.

"The thyroid glands were intensely sclerosed, the thyroid vesicles containing no colloid material, but being full of cells. No lymphatics were to be found. In the thymus gland a similarly advanced sclerosis was present."

The important points in Baudouin's results are:—

(1) Changes in the external group of the anterior horn cells.

(2) Smallness of the anterior roots suggesting arrest in development.

(3) Abnormality of the peripheral nerve trunks, suggesting an arrest of development of the nerve fibres.

(4) Intense sclerosis and regressive changes in the muscles.

(5) Marked sclerosis of the thyroid gland and of the thymus gland.

In the fragment of muscle that was removed from Bing's patient all that was found was a possible slight increase in the nuclei; otherwise the muscle appeared normal.

When a careful comparison of these pathological results, which seem somewhat at variance, is made, the difference between them seems to be rather one of degree of pathological change than a fundamental difference. It is quite obvious from the reports that a finer scrutiny of delicate changes was made by Baudouin than was made by Spiller. It is quite possible that the essential differences in the two results—the affection of the anterior horn-cells, of the anterior roots, and of the nerve trunks, all of which were said to be normal in Spiller's case—may be due to differences in the intensity of the disease and different methods of examination in the two cases. From the clinical report of Spiller's case we think that Bing is hardly justified in his contention that the amyotonic nature of Spiller's case is "höchst problematisch." There was no positive finding in Spiller's case, which is at variance with Baudouin's result, and as regards the condition of the muscles and of the thymus gland they are strikingly in unison.

That his pathological results should have led Baudouin to the conclusion that the sum of the anatomical changes is just such as is met with in cases of myopathy is of great interest, and is a very strong argument for those who would include amyotonia as a subclass among the myopathies. The essential pathology of the myopathies, however, is far from being well understood, and it is at least possible that the two conditions, amyotonia and myopathy, while having an essentially distinct pathology, as they have clinical aspect and course, may yet show almost identical changes in the nervous and muscular systems. While holding an open mind upon the subject, we think that the pathological evidence at present available, although suggestive, is not sufficient to decide the question of the relation of the two diseases.

The condition of arrest of development in the lower motor neurones found by Baudouin is well in accord with the congenital nature of the disease and with the presence of the symptoms at the time of birth in a high majority of the cases. Such arrest of development fits in very well with a clinical course of gradual improvement, for in the most typical example of arrest of development of certain elements of the nervous system during intra-uterine life, cerebral diplegia of the paraplegic type (Little's disease), in which there is an arrest of development of the pyramidal neurones of the paracentral region which supply the lumbar enlargement of the spinal cord, a tendency to gradual recovery is the rule.

There is one other parallel between diplegia and amyotonia which is worthy of note, and it is that both diseases, though in a high majority of cases congenital and evident at birth, in a minority of cases make their appearance some time subsequent to birth, and may develop rapidly after acute illness.

If Baudouin's deduction that the changes he found in the anterior roots and in the nerve trunks represent a condition of arrested development is the correct one, it seems probable that amyotonia is a disease of the lower motor neurone and muscle rather than a disease confined to the muscle itself.

It has been suggested by several writers, and especially by Cattaneo, that amyotonia may be due to a congenital deficiency of some internal secretion which controls muscular tone. The physiological importance of the suprarenal glands, as regards the muscle tone, and the involvement of certain internal secretory glands, at once come to mind in this connection. While there is no evidence whatever that there is any such internal secretory disorder in amyotonia, there is very distinct evidence against this theory. In the first place the distribution of amyotonia, the arms being affected most in one case, the legs alone affected in another case, the trunk escaping completely where all four extremities were severely affected in a third case, is not the distribution that would occur from any disorder of internal secretion that must of necessity affect all the muscles of the body alike. Secondly, the tendency to improve would be very difficult to explain on the ground of a congenital deficiency of an internal secretion.

It has been suggested that a condition akin to infantile myxœdema exists in cases of amyotonia, and, as far as we are able to judge, the suggestion is based upon the occurrence of chronic œdema of the legs in one case (18). Œdema has been absent in all the cases except one, and it was absent in Baudouin's case, in which there was marked sclerosis of the thyroid gland. None of the signs of thyroid insufficiency—such as arrest of growth, mental hebetude, &c., have been present in any of the cases.

CLINICAL ABSTRACT OF TWENTY-ONE CASES FROM THE LITERATURE, WITH A DETAILED ACCOUNT OF FOUR NEW CASES.

Case 1 (Batten [1]).—Female, aged 6. She was the tenth of eleven children, the rest being healthy. Full term, breech presentation, easy birth. She was said to have been born "exactly as she is at the present time," and never to have improved at all. She was very intelligent, and talked well at 2 years of age. The body was very small for the age, and the limbs were thin and the muscles small, but there was no local wasting. The hands and feet were remarkably long and narrow. There was no absolute paralysis anywhere, but she could make no attempt to stand, and could not sit up unless placed in that position. She could feed herself, and she tried to sew and to knit. Special senses, sensibility, muscular sense and sphincters were unaffected. There was slight contracture at both knee- and hip-joints. The knee-jerks were absent.

Case 2 (Batten [1]).—Male, aged 7. He was the ninth of eleven children, the rest being unaffected. Birth was natural, and he was bottle-fed. The body was noticed to be very small at birth and the legs to be contractured. He was never able to walk. The limbs were thin, but there was no local wasting, and the hands and feet were very long. All movements could be performed, but all were weak excepting those of the face, which, however, seemed expressionless. There was marked contracture of the hamstrings. The muscles reacted to strong faradic currents. The knee-jerks were absent.

Case 3 (Batten [1]).—Male, aged 6. He was the third of a family of four children, and the others were said to be healthy. He had never been able to stand or walk; he could sit up but he could not kneel; he talked well and was quite intelligent. His body was thin and small; his means of progression was to lie on the floor and roll round and round upon his longitudinal axis. The muscular development was very small, but there was no local atrophy or hypertrophy. All movements could be performed with the arms, but he was unable to extend the legs or the thighs owing to the weakness of the quadriceps, and he could not flex the thighs. The extensors and flexors of the feet were weak, but he could make all the movements of the toes. The muscles of the back and of the abdomen were weak. The movements of the face were well performed. Only the strongest faradic current produced reaction in most of the muscles, but no response was obtained in the quadriceps or in the glutei. The knee-jerks were absent, the plantar reflexes were of the flexor type.

Case 4 (Baudouin [2]).—Female, aged four months. Family history negative Natural birth at full term. Ever since the birth of the child its neck, trunk, arms and legs remained completely immobile. On examination, the cranial nerves were normal, except for slight internal strabismus of the right eye. Could suck, swallow, smile, or cry. Double pes varus, with a slight tendency to the equinus position. Complete flaccid paralysis of voluntary movement in trunk and limbs, with the exception of feeble movements of the fingers and toes. Absolute loss of tone in the muscles, which were very difficult to feel because of well-developed superficial tissues, especially in legs. Shallow thoracic breathing; absence of deep reflexes and of plantar reflexes, no sphincter impairment: no alteration in sensation, no response in muscles to a strong faradic current, no sign of rickets or congenital syphilis.

Under treatment in hospital general improvement, but no change in muscular condition; child died of broncho-pneumonia a month later. The results of the pathological examination are quoted above

Case 5 (Berti [6]).—Male, three days old Family history negative; well developed and born naturally at full term. Flaccid paralysis of arms and legs; flaccidity of all muscles. Drawing in of sternum and lower ribs with inspiration. No loss of sensation, absence of superficial and deep reflexes, uncertain reaction to faradism in paralysed limbs; no impairment of sphincters. After three weeks, improvement in respiration, some movement of one arm in response to stimuli, and slight flexion of fingers on pricking palm of hand. Subsequent history unknown.

Case 6 (Berti [6]).—Female, aged 5. Negative family history; normal birth. From birth until child was about a year old, no voluntary movements of trunk or limbs, with exception of very slight movement in one arm and fingers, better movements of head. Gradual improvement in arms, and after about one and a half years signs of life in lower extremities. Since, steady though slow progress. At end of five years improvement rather quicker. When seen then all movements of limbs present, though feeble and slow; able to stand and to rise from the floor, unsteady on legs; muscles all very flaccid and atonic; faradic excitability reduced; cutaneous reflexes active, knee-jerks diminished, sometimes uncertain. No alteration in sensation; no sphincter trouble. Still further improvement with arsenic and strychnine.

Case 7 (Bing [7]).—Male, aged 3½. Family history negative; normal birth. Congenital bilateral pes varus. Parents stated that since birth there had been great weakness and softness of the muscles, child could neither stand nor walk. When examined, it was seen that there was no voluntary movement of the legs, where, however, the muscles were well developed. Child could not sit up properly, nor could it hold its head up for more than a minute or two. Arms could be moved about but weakly; arm muscles very flabby. Could drag itself about on the floor by the help of its hands. Great freedom of passive movement at all joints. Knee-jerks absent. No sensory changes, no sphincter impairment. Muscles reacted to both electrical currents; response to galvanism diminished, but no reaction of degeneration.

Case 8 (Carey Coombs [11]).—Female, aged 10. Family history negative. Natural birth at full term. Within half an hour of her birth one hand was noticed to be peculiarly flabby and loose. When she began to learn to walk it was found that her legs gave way under her, when she was only 2½ years old the fact that her calves were very small was remarked upon. Till she was 7 or 8 her ankles turned over so readily as to cause a serious disability, as she often fell. Her hands and their possibilities have always been a source of entertainment to her friends; at school this has developed to such an embarrassing degree that her parents have been obliged to forbid her "showing off" to her schoolfellows.

The orbiculares palpebrarum seemed slack and toneless, but not appreciably weak. Muscles of mastication, with those of tongue and lips, not atonic. Universal defectiveness of power accompanied by, and apparently proportionate to, a poor development of the muscles generally; distal parts of limbs seemed to have suffered more than the proximal; this weakness and poor development were evenly distributed. Muscles could be felt quite distinctly, though they were small, soft, and doughy. The impression given was different from that derived from fingering atrophied muscles. The most striking feature was the remarkable hypotonicity of the muscles; the result was an abnormal freedom of passive movement at various joints. The knuckles could be made to touch the back of the wrist, the palm of the hand could be pressed against the front of the wrist. Lower limbs also hypotonic, but not to the same degree as the arms; very distinct indications of hypotonicity in the muscles of the trunk also. Knee-jerks and Achilles-jerks were present on both sides, but the tendon reflexes of the upper extremities could not be elicited. Electrical reactions showed definite decrease of muscular excitability equally to both currents, roughly proportionate to the diminution in volume and power of the muscles. No diminution or other perversion of sensation, special or cutaneous, nothing of the nature of trophic change, apart from the muscles.

Under treatment there has been produced a definite increase in the muscular strength of the legs, though the hands do not respond. The muscles, according to the parents, have not grown flabbier since the early age at which it was discovered that something was wrong.

Case 9 (Cattaneo [8]).—Female, aged four months. Consumptive family history; natural birth. During the pregnancy mother did not experience quickening. Breast-fed at first. At birth it was noticed that the child did not move its arms or legs; father thinks it can now move its arms. Cannot hold its head up.

Well nourished, with normally developed musculature; slight kyphotic curve in cervical region; limbs immobile, presenting the appearance of a flaccid paralysis, except for slight movements of hands and feet. Cutaneous and deep reflexes were absent; no sensory change; very feeble muscle twitches, with strong electrical stimulation (both currents) in arms and legs. (In this case the existence of a scar over the lumbo-sacral region suggested a possible spina bifida occulta, but the characteristic signs of that condition were wanting.)

Case 10 (Collier and Wilson).—H. A. C., a boy, aged 4 years and 3 months, was admitted into the National Hospital on February 18, 1907. The parents were young and healthy. There was no history of syphilis, and the mother had had neither miscarriage nor stillborn children. There were three children, the eldest being a healthy girl of 7; the second was the patient, and the third was a healthy girl of eighteen months. The family history was unimportant.

The patient was born at full term, and delivery was natural At birth he was well shaped but thin; he was breast-fed from the time of birth, he was delicate, and always had trouble with the chest; he had suffered with measles,

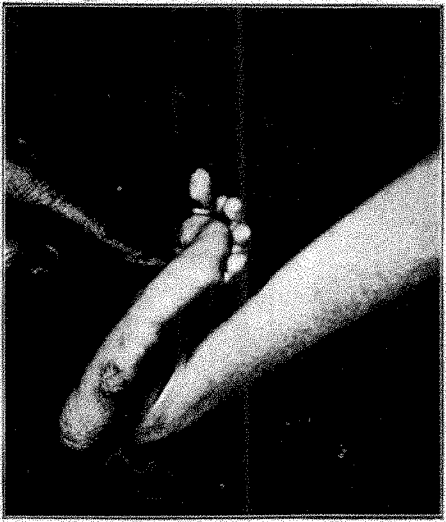

FIG. 1.

From Case 10, showing the long pad-like foot and the extreme dorsiflexion of the ankle.

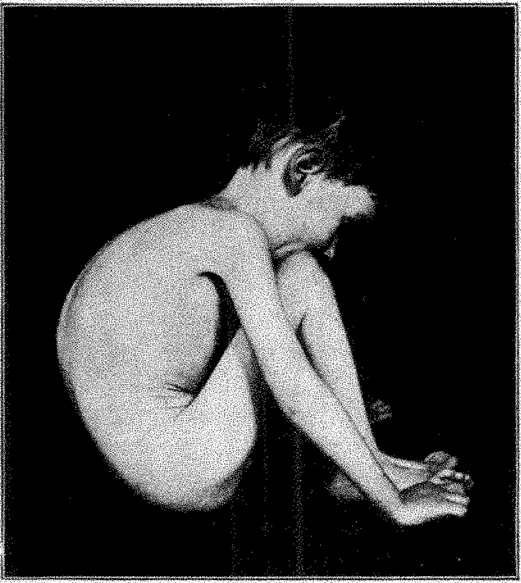

FIG. 2.

From Case 10, showing the bunched-up attitude in sitting.

whooping-cough, varicella, bronchitis and pneumonia; he has been constantly attending hospitals since he was six weeks old. He began to talk at the usual time.

From the time of birth his mother noticed that the position which the legs assumed naturally was one of flexure at hip and knee and extreme dorsiflexion at the ankle, so that the backs of the feet touched the shins. The legs were very weak and always absolutely limp. The arms were weak and very limp. He could never hold his head erect, and the body "bunched up" when he was sitting. He had gradually improved in power ever since birth, but he could not stand for more than a second or two, and the legs would not go straight. He had never suffered pain, and had had no sphincter trouble. The legs were often cold and blue, and he had been much troubled with chilblains. The mother was sure he had never had any loss of sensibility in the legs; he had always been bright and intelligent.

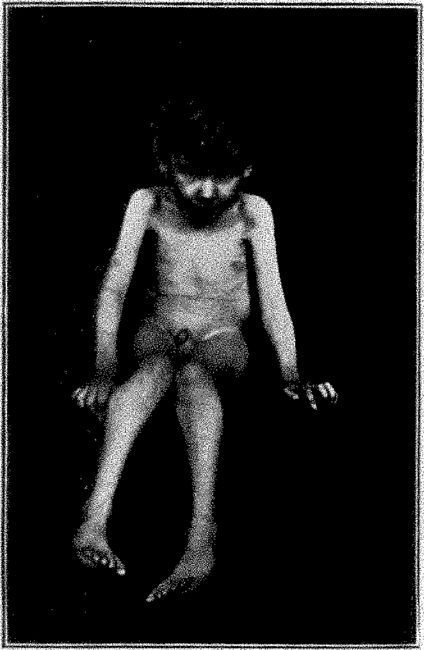

FIG. 3.

From Case 10, showing the general smallness of musculature and the long feet.

On admission: Patient was a small, thin, and peculiarly soft, limp child, of good colour. Hair normal. The ear, palate and cranial vault were well shaped. The fontanelle was closed. The teeth were extremely carious, most of them being black, with the enamel gone and with transverse grooves. The thoracic and abdominal viscera seemed normal, except that a slight systolic murmur was present over the whole extent of the sternum and that there were signs of slight broncho-pneumonia. The abdomen was scaphoid in shape and the waist *en taille de guêpe*, owing to the prominence of the costal margins and the laxity of the muscles of the abdominal wall.

Intelligence and attention were very good; he spoke well for his age. No giddiness nor fits had occurred. The special senses and the optic discs were normal; the cranial nerves were normal. The muscles of mastication were not powerful, neither were the facial muscles. Expression and smiling were normal.

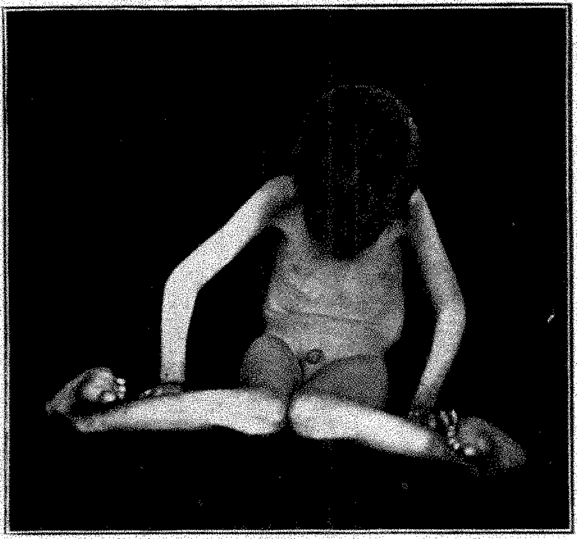

FIG. 4.

From Case 10. A usual attitude of this patient. The difficulty of holding up the head and the extreme external rotation at the hips and dorsiflexion at the ankles are well shown.

The musculature throughout the body and limbs was small and seemed absolutely atonic, and the joint ligaments were relaxed, so that the limbs could be placed into all sorts of fantastic positions without causing any discomfort.

On palpation it was impossible anywhere to distinguish the limits between subcutaneous tissue and muscles, even when the latter were in voluntary contraction. The muscular regions had a peculiarly soft velvety feel, quite different from the feel of the limbs of a normal child. A limb held by its proximal end could be shaken like a flail.

There was marked contracture of the ilio-psoas muscles, adductors and hamstrings upon both sides, but none of the gastrocnemius. All voluntary movements of all the muscles of the body could be performed quickly and with normal range, the above-mentioned contractures being taken into account, but the power was very feeble.

There was no deformity of the body or limbs beyond the contractures. The vertebral column bowed in the sitting position, but the curve disappeared on holding the child from the shoulders. There was no webbing of fingers or toes.

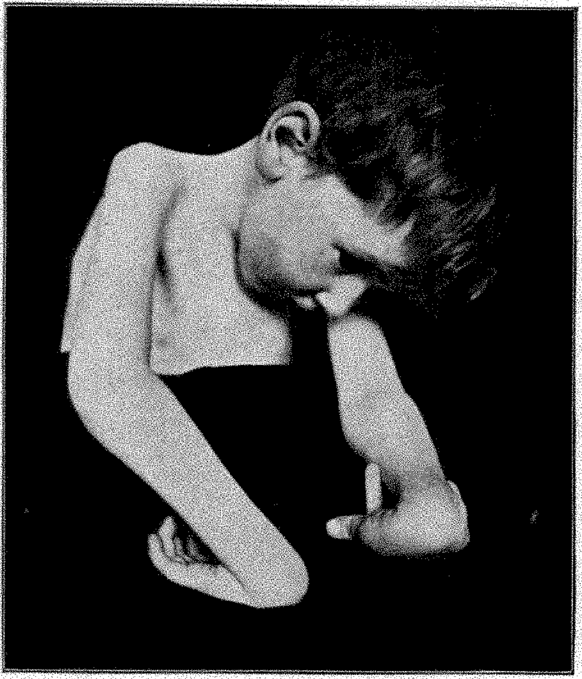

Fig. 5.

From Case 10, showing the extreme flexion possible at the wrists.

The plantar surfaces of the feet were almost flat, there being no ball to the great toe. The soles were very soft, and were like long pads, which spread out gradually on either side from the heel forwards.

The bones were small and very easily bent, the radius and ulna and the tibia and fibula of either side being easily touched together by the pressure of the observer's thumb and index finger. Skiagrams showed that the ossification of the bones of the limbs was normal for a child of the patient's age.

There appeared to be no objective sensory change, but it was most remarkable that this child exhibited no concern and complained of no pain when strong faradic stimuli were applied to the limbs. Muscular sense and sense of position were possibly defective.

Faradic excitability was considerably lowered, strong stimuli being required to produce contraction. Galvanic excitability was slightly below normal, there being no change in the polar reaction.

The deep reflexes were absent without exception. The abdominal reflexes were present. On stimulating the soles of the feet the response seemed always to be a voluntary action, so that it was difficult to ascertain the actual nature of the plantar reflexes; probably they were flexor. No foot-clonus; sphincters normal.

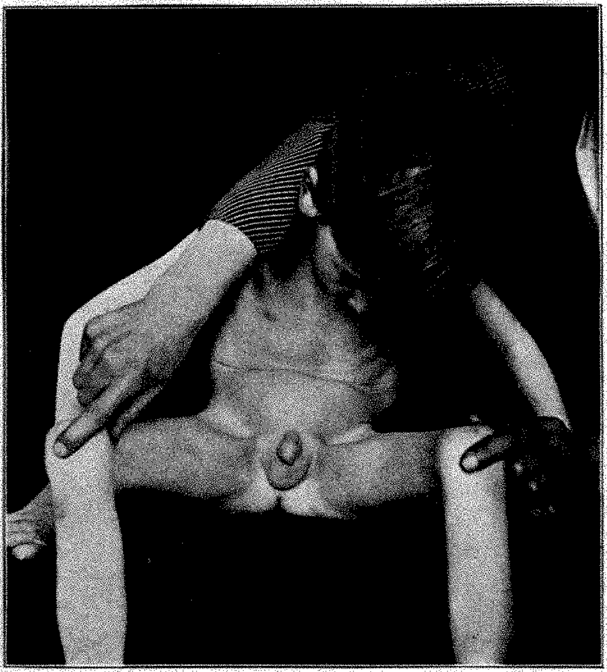

FIG. 6.

From Case 10, showing the adductor contracture at the hips.

Case 11 (Collier and Wilson).—A little boy, aged 7, was seen in consultation with Dr. Whait, of Hampstead, in May, 1907, suffering with universal weakness since birth and bilateral club-foot.

It was stated that several members of the mother's family were unable to close their eyes properly, and that the mother of the patient was very weak in her limbs when a child, but that she had perfectly recovered. She had had three children, the patient being the eldest. The second, a girl, is said to have had something wrong with the limbs; she died at the age of 2. The third child died within a few days of birth.

The present patient was born in South Africa during the war, and the mother had been subjected to considerable hardships and privations during her pregnancy, but had no definite illness. The child was born at full term. It was noticed directly after birth that his head was large and heavy, and that he could not hold it up. Soon after it was apparent that he was unnaturally limp, and he had no strength to move except in his back, which has always been the strongest part of him. He could not grasp anything with his hands until he was 3 years old. The club-foot was noticeable soon after birth, and was so marked at the age of 1 year that tenotomies were performed. He was always fairly intelligent. A photograph at the age of 3 shows that the facial peculiarities which will be subsequently described were quite as apparent then as at the present time. He was never able to walk. He improved slowly, and at the age of 3 he was brought to England, and since this time he has been continuously under the care of Dr. Whait, and

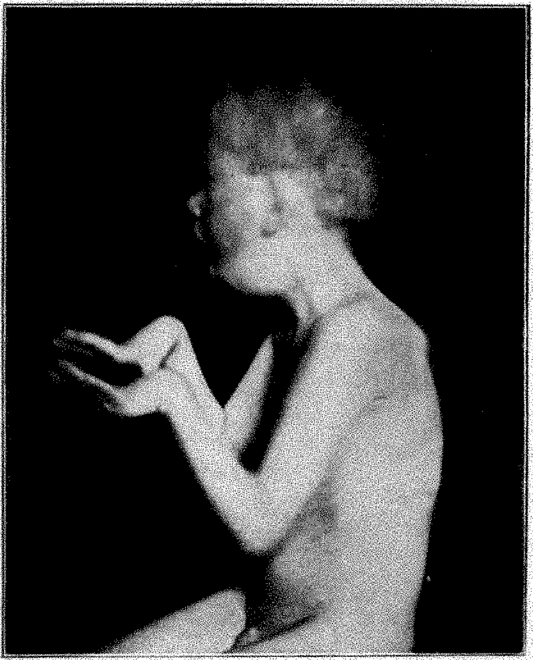

Fig. 7.

From Case 11, showing the double-jointed hands.

has slowly improved all the time. When Dr. Whait first saw him the head was markedly large, the facial muscles were weak, and there was inability to close the eyes completely. There was universal flaccidity and weakness, most marked in the upper extremities, where all the joints were flail-like. In the lower extremities the muscles above the knees were flaccid, but there were marked contractures of the muscles of the legs, both feet being found in a dropped and inverted position.

The muscles were small and soft, and it was impossible by palpation to distinguish between the muscle and the overlying skin and subcutaneous tissue.

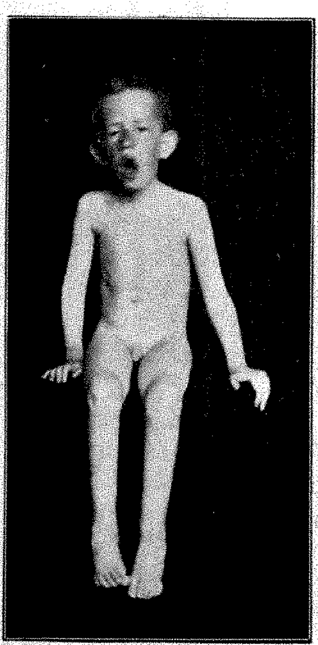

FIG. 8.
From Case 11. Maximum effort to close eyes.

Every muscle in the body contracted voluntarily, but so feebly that no useful act could be performed with the limbs.

All the muscles reacted to faradism, a much stronger stimulus than the normal being necessary to elicit contraction. It seemed that the child was able to bear faradic stimuli more easily than a normal child.

The aspect of the face was peculiar, the frontal region being unduly large, the lower face and chin being unduly small. The mouth was always open. The distance from the articular process of the mandible to the angle was so short that in closing the teeth together the posterior molar teeth came in contact while the incisors were still ½ in. apart. This condition may have been a developmental peculiarity or it may have resulted from contracture of the masseters and pterygoids preventing the growth of the vertical process of the mandible. The triangular face, open mouth, and feebleness of the facial muscles gave the child an imbecile expression out of all relation to the very fair degree of intelligence which he possessed. All the facial muscles contracted voluntarily, but very feebly. The eyes could not be completely closed, and when crying the absence of facial contortion was most remarkable. The child spoke well, but with an articulatory defect which was obviously due to his inability to close the lips and make the front teeth meet.

The special senses were normal; there was no strabismus or nystagmus.

Sensibility was natural, with the reservation that strong faradic stimulation seemed to be very easily borne. There was no sphincter trouble.

The superficial reflexes were normal. The deep reflexes were entirely absent.

The child was circumcized by Dr. Whait, and it was found that he was hæmophilic; the bleeding was not arrested for many days.

From this time up to the present there has been very slow but regular improvement, and now the child can make effectual use of his hands. He cannot stand yet and, the deformity of the feet standing much in the way in this respect, a double tarsectomy has recently been performed.

In the early part of the present year (1907) it was noticed that for the first time a feeble knee-jerk could be obtained upon both sides. At present the knee-jerks are easily obtained, but all other deep reflexes are still absent.

When again examined in March, 1908, this patient had made good further progress, and could walk a little without support.

Case 12 (Collier and Wilson).—S. A. I., a little boy, aged 5¼, was brought to the National Hospital in February, 1907. His mother stated that he had been backward since birth, that he was very clumsy with his hands, and that he was unable to use his legs.

The parents were healthy, and there was no history of any family disease, except that the mother's aunt was said to have had epilepsy. There were seven children, of which the patient was the fifth. Two of these had died in early infancy, one aged 11 months of blood poisoning, and one aged 7 months of whooping-cough and convulsions. The other children were healthy. The mother had had good health during the pregnancy, and birth was natural and easy. The child was breast fed till 15 months old. The mother, who was not at all an observant woman, said that she had not noticed anything wrong with the child during the first six months, though she had remarked that he could put his limbs into extraordinary positions quite unlike her other children. After this time she began to notice that his legs were weak. He was late at attempting to stand, and never accomplished anything more than standing up when holding on to anything. He could never walk alone. This ability to stand when supported lasted only two months, after which he gradually became weaker and weaker on the legs. That the mother had never noticed anything wrong with the upper extremities, even up to the time when the child came under our care, is a good proof of her extreme lack of observation, for the affection of the arms was most noticeable.

On admission, he was a pale, thin, starved-looking child of average height. His intelligence was unusually good for his age. He had never had fits. The special senses and the cranial nerves were normal. The facial musculature was well developed and symmetrical, and the facial movements were good; there was no difficulty in speaking or swallowing, and the tongue, which was protruded straight, was normal in size and was not tremulous.

All the muscles of the upper extremities were below the normal size, but all voluntary movements could be performed with normal range and fair power. There was most absolute hypotonia of all the muscles with marked relaxation of all the ligaments, so that all the joints were more or less flail-like. The upper extremities could be folded behind the back and could be put into many extraordinary positions without causing the least pain.

The muscles of the neck and of the trunk were thin and weak. He could only just raise the head from the bed when lying in the supine position, and sat up with difficulty, the body being bunched up, with a tendency to kyphosis.

The muscles of the lower extremities were flabby, but they had a firmer feel to the touch than had the muscles of the upper extremity. There was slight contracture of the flexors of the thighs and of the hamstrings, and a more decided contracture of the muscles of the feet, giving rise to a considerable degree of pes cavus. All voluntary movements were possible and were of fairly good range, except in so far as they were hindered by the contractures, and the power was fair; but the extensors were weaker than the flexors at all joints. The excitability of the muscles to faradism was markedly diminished, and the child showed no signs of pain when strong faradism was applied. The reaction to galvanism was normal, sensibility was normal and there was no affection of the sphincters. The superficial reflexes were normal. The deep reflexes were entirely absent. This patient is improving markedly in power under treatment.

Case 13 (Collier and Wilson).—M. S., a girl, aged 1 year and 8 months, was admitted into the National Hospital, under the care of Dr. Beevor, in September, 1907, suffering from loss of power in both legs.

Both parents were healthy, and there was no history that any member of the family had been similarly affected. This little girl was the only child of her mother, who had enjoyed the best of health during her pregnancy and had felt normal fœtal movements. She was born at full term and was breast fed for ten months; she was quite well and thriving till she was twelve months old, when she had already cut six teeth. At this time she was seized with an attack of bronchitis, and was ill for a month. She had no rash and was not feverish, but at the end of this illness it was noticed that she could not move the legs at all. The arms were said not to have been affected. For the next six months there was absolutely no power of movement in the legs, but in the subsequent two months which preceded admission she began to move the legs and the power in them gradually increased.

On admission she was fairly developed for her age, but she was thin and somewhat pot-bellied. The special senses and the cranial nerves were normal, and her intelligence was fair. The movements of the face were strongly performed. There was fair power in the neck and trunk. All movements of the upper extremities were performed, and with fair power; but the arms were very flaccid, and movements in all directions were much more free than is normal. There was hyperextension at both elbows, and if with the arm held in the observer's hand the forearm was allowed to fall back passively into the position of extension, the olecranon came in contact with the humerus with an audible tap, well demonstrating the condition of flaccidity of the muscles. Both lower extremities were in a condition of severe flaccid palsy; they could be placed in the most unnatural positions without pain, and they remained in any position in which they were placed. Both feet could be dorsiflexed with ease to the extent that the whole length of the dorsum of the foot was in contact with the tibia. The usual position that the limbs assumed was one of slight flexion with extreme external rotation at the hips, knees slightly flexed, the feet everted, and the toes pointed.

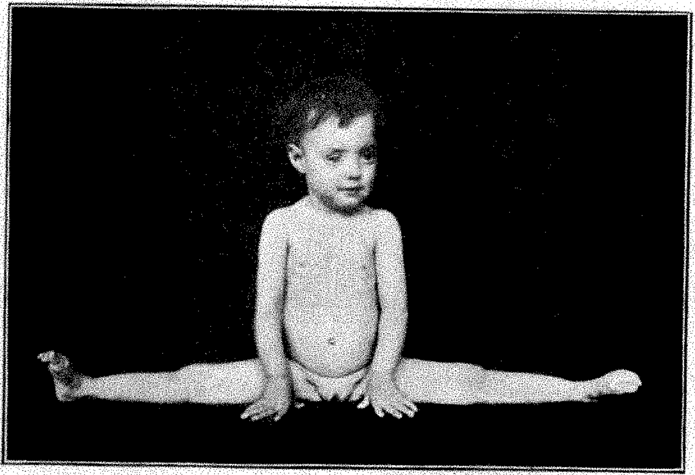

FIG. 9.

From Case 13. Usual attitude. The affection is of the lower extremities mainly.

In the lower extremities the musculature was absolutely atonic. The limbs had a peculiar soft velvety feel, the skin, subcutaneous tissue, and underlying muscle being quite indistinguishable to the touch. All the movements of both lower extremities were very weak and could be resisted with great ease. Nevertheless, the voluntary control which the child had over them was very considerable. She could flex and extend all the joints without exception, and she could abduct and adduct the thighs. There was slight flexor contracture at the hips, and to a less extent also at the knee-joints.

There was absolutely no trace of any local muscular wasting throughout the body—the lower part of the pectoralis major and the posterior axillary muscles were as well developed as the other muscles of the limbs. Very striking indeed was the extreme flaccidity of the hands and feet, which, when shaken passively, performed loose, flail-like movements in all directions.

Sensibility to touch was normal everywhere; but upon the limbs the child did not seem to take due notice of a slight prick, though a severe prick at once produced the usual signs of pain. It was very obvious that she bore the strong faradic stimuli necessary to obtain contraction in the muscles with much greater equanimity than does a normal child. The deep reflexes were everywhere absent. The plantar reflexes were of the flexor type.

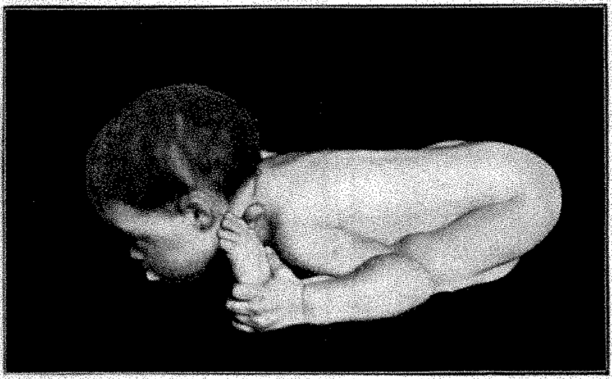

FIG. 10.
From Case 13. A characteristic attitude.

The electrical excitability of the muscles to faradism was everywhere present, but a powerful stimulus was necessary to produce a small twitch. All the muscles responded to galvanism with a normal polar reaction, and without any slow contraction.

After this patient had been in hospital for three months under regular massage, tonic treatment and good feeding, very marked improvement in the power of all the muscles was noticeable. The wrist- and elbow-jerks returned and were readily obtainable, but the knee-jerks are still absent.

Case 14 (Comby [9]).—Male, aged 8. When seen first in September, 1905, he could neither walk nor stand, and when he sat up his spinal column showed a pronounced kyphosis. The child was well fed, had put on weight regularly and revealed no trace of rickets.

An intelligent little boy, the only defect he presented was in his muscles which were everywhere soft, but not atrophic. He could move his legs in bed but they were not strong enough to support him. All deep reflexes were absent. Sensation normal.

Case 15 (Comby [10]).—Male, aged 4 months. At the age of one month he had an attack of diarrhœa, and the next day there was noticed a general paralysis of the infant's muscles; it could neither hold its head up nor move its limbs. After eight days considerable improvement, the legs alone remained paralysed.

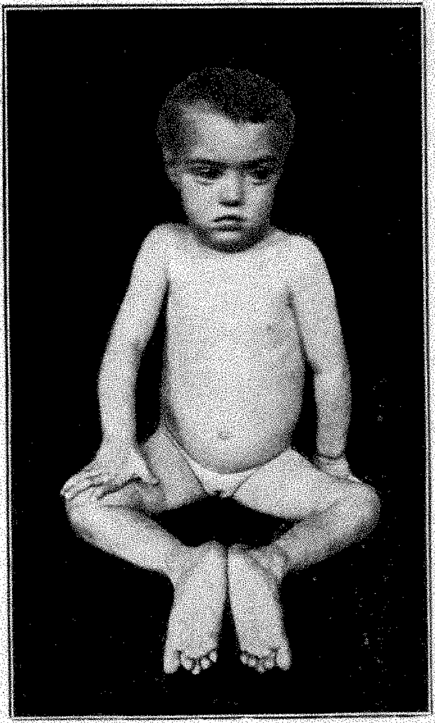

FIG. 11.

From Case 13. Usual attitude. The affection is of the lower extremities.

On examination the latter were immobile; no appreciable muscular wasting anywhere; sensation normal; knee-jerks absent. The head rolled from side to side. When the child cried, the abdominal wall bulged on the right side; dorsal kypho-scoliosis. Electrical examination showed a hypo-excitability of the back of the right thigh and of the right calf; no reaction of degeneration. This result did not correspond with the general muscular inertia of the child.

When seen eleven months later the child looked quite well, but the muscular atonia persisted.

Case 16 (Iovane [12]).—Male, aged 3 months. Family history negative. Normal pregnancy; natural birth at full term. The child appeared perfectly healthy and was able to take the breast, but it was noticed on the first day that there was no voluntary movement of arms or legs, and that head rolled about on trunk. Seen three months later, child appeared in excellent health. No atrophy of muscles; face unaffected; no difficulty in swallowing; sphincters normal. Flaccid paralysis, with absolute atonia of muscles of arms and legs; feeble movements of distal segments of arms. Muscles of trunk as atonic as those of limbs. Shallow thoracic breathing. No alteration in sensation; deep reflexes absent; plantars absent, but abdominal reflexes present. Practically no response to galvanic stimulation of muscles, slight to faradism. Child died two months later of broncho-pneumonia.

Case 17 (Kundt [13]).—Female, aged 18 months. Negative family history Natural birth at full term. During the pregnancy the mother noticed quickening just as with her other children. Bottle fed. At first no movements of the legs at all, after six months the child began to move its feet and ankles. Gradual improvement, but still unable to stand or walk. When seen could sit up, and arms seemed all right. Well developed and nourished when first under observation. Absolute hypotonia and soft flabby feeling of the muscles of the legs, but their temperature and colour were normal. Great laxity at all the leg joints. Active spontaneous movements only in toes, feet, and rarely of lower leg. Painful stimuli, however, made the child move its legs at knee and hip, not so well on right as on left side. Knee-jerks absent on both sides, left Achillis-jerk present. No muscular response to mechanical stimuli Muscles of leg reacted fairly to both forms of electric current, with the exception of the right tibialis anticus. Above the knee, however, there was practically no response except a slight one in the hamstrings and the left adductor group. No reaction of degeneration Cranial nerves, special sense organs, and intelligence normal. Radiographs of the bones showed a normal condition.

Some general improvement in the muscles of the legs with four months electrical treatment. Improvement in the Achillis-jerks.

Case 18 (Leclerc [14]).—Female, aged 4. The parents were healthy. The mother had had four pregnancies, the first ended in a miscarriage at the second month, the second child was stillborn at eight months, the third child was born weakly at full term and died at the age of two months, the last child was the patient During the pregnancy the mother was well in health and felt normal fœtal movements. The child was born twenty days before term and the birth was natural. She appeared quite normal at birth and for the following seven weeks, when she was seized with broncho-pneumonia. A few days subsequently she developed a universal flaccid paralysis, the face and muscles of deglutition escaping. From this time onwards she improved slowly but progressively. At the age of 4 her condition was as follows: There was extreme flaccidity in all four limbs, with relaxation of all the ligaments and flail joints. Every muscle could be moved voluntarily, but the power was so feeble that no effective movement could be made; she was, however, able to hold the head up, and the muscles supplied by the cranial nerves seemed intact. The muscles were small, but there was no local atrophy, and the muscles gave to the touch a feeling of peculiar softness. The skin of the lower extremities showed a degree of hard œdema comparable with that of myxœdema. The knee-jerks were always absent. The general health and the state of nourishment were good and there were no signs of rickets. The electrical reactions were not reported.

Case 19 (Lugenbuhl [15])—Female, aged 5 months. Maternal grandmother a tabetic, otherwise family history negative. Normal birth at full time. During pregnancy, quickening felt in usual way by mother. At birth it was noticed that limbs were motionless and flabby. Four weeks later, slight finger movements; thoracic muscles badly developed and functioning poorly; similarly with muscles of neck. Cutaneous and deep reflexes absent; normal sensation, no response to either faradic or galvanic stimulation. Facial musculature quite unaffected, and active to electrical currents. No affection of the thymus discoverable.

Four months of electrical and massage treatment have improved condition, child can now move toes, feet, hands, forearms.

Case 20 (Oppenheim [18]).—Child, aged 19 months, sex not stated. Natural birth. Family history negative. It was noticed not long after birth that the child could not move its limbs, though the trunk and face muscles appeared to function normally. The weakness was associated with extraordinary flabbiness of the muscles. Nine months passed before the child began to move its arms, and only in the last few weeks has it begun to move its legs, following on electrical treatment. It is well developed and nourished, with little if any reduction in the volume of the muscles, which felt doughy. Their tonus was markedly diminished; the tendon reflexes were all absent. The muscles did not react to mechanical stimuli nor to strong electrical stimuli, with the exception of feeble twitches which were obtained in the peroneus. No alteration in sensation; no impairment of sphincter control.

Case 21 (Rosenberg [21]).—Male, aged 2½. Family history negative. Mother stated that having experienced no quickening during the pregnancy she was afraid the child would be stillborn. The value of this statement is somewhat discounted by fact that the only other pregnancy ended in a three months abortion. Natural birth at full term. Bottle fed. Always able to suck and to swallow. Movements of head, eyes, face and arms always good; child learned to sit up at 7 months The defect of leg movement escaped the notice of the parents till the child was 11 months, when they noticed knees and hips always gave way with the child's weight. Could neither stand nor walk. Well developed and nourished. No movement of thigh or leg, only of foot and toes. With painful stimuli, however, it was found that child could move legs at hip and knee, though feebly. Toe and foot movements fairly active. No atrophy of leg musculature; skin natural colour and temperature. Great hypotonia of leg muscles, but slight contracture of the hamstrings. Absence of knee- and Achillis-jerks. Proximal muscles of legs felt more doughy than the distal. Former did not react at all, either to mechanical or electrical stimuli, whereas with strong currents a slight response was obtained from the peronei. No change in sensation. No sphincter trouble. Cutaneous reflexes not elicited. Deep reflexes present in the arms. Head and arm movements fair. No sign of rickets. Cranial nerves normal.

After thirty-one months treatment considerable improvement in movements at hip and knee.

Case 22 (Schüller [22]).—Male, aged 19 months. According to the mother's account, child was always weak, though never really ill. After learning to sit and to stand, during the last nine months it has gradually ceased to do either, and now it can no longer sit upright well. Very pronounced hypotonia of the leg muscles, without any wasting; absence of deep reflexes; great quantitative diminution in electrical excitability. Active movements of the legs limited; sensation normal; condition of bones and joints normal.

Case 23 (Spiller [25]).—Male, aged 22 months. Negative family history. Normal birth at full term. Breast fed until date of admission to hospital. When he was given cow's milk in an attempt to wean him he would always spit it out, and of late, since he had been taken from the breast, he had swallowed with some difficulty. He had never at any time been able to hold anything in his hand. He was well developed for a baby of his age. Muscles not wasted, flesh soft and flabby. Limbs were moved voluntarily at all joints, and there was merely weakness present. Deep reflexes in the legs not elicited. Sticking any of the limbs with a pin causes the irritated limb to be drawn away with considerable force. The hypotonicity of the limbs, especially the lower, was very great. Could sit alone only for a minute or two, and only when he is balanced, but his head fell slightly forward. Had never been able to stand, muscles of limbs react to faradic current. Atony of the abdominal walls.

When in hospital it could not be induced to take food, and was always fed nasally. It died not long afterwards, and the pathological findings are given above.

Case 24 (Tobler [26]).—Male, aged 1¾ when first seen, and observed for three subsequent years. Negative family history. Natural birth at full time. Breast fed for six months. From outset it was remarked that the child made little or no spontaneous movement. When first examined, plump and well nourished. No signs of rickets. Musculature well developed and symmetrical, but very weak and flabby. Kyphosis of the vertebral column; absolute tonelessness of limbs; great laxity of joint structures. No paralysis; on the contrary, there was movement both of arms and legs, of the former more particularly, but the movements were languid and weak. It was noted that they were better peripherally than proximally. Rose with great difficulty to a sitting position, but once sitting up could remain so. Tongue and eye movements normal; facial musculature rather inactive. Knee-jerks not obtained; electrical excitability to both forms of current either diminished or lost. Sensibility to pain and to electrical stimulation was not affected.

Two years later the child had grown mentally and physically; was well nourished, could feed itself, and seemed to try to make all the use it can of its limbs; still quite unable to stand. A few months later it died, apparently from diphtheria. No autopsy was obtained.

Case 25 (Variot and Devillers [27]).—Female, aged 6 months at its death. Mother remarked very little, and very feeble quickening during pregnancy. From the beginning the parents noticed the peculiar position of the child's arms, which were flexed at the elbow and adducted at the shoulders. Both arms and legs were immobile, and the whole of the musculature of the body was most abnormally flaccid. The head rolled about indifferently if it was not supported. When the arms or legs were lifted, they fell back as limply as the limbs in polio-myelitis. When the child was seated a marked spinal kyphosis was noticeable, which disappeared when the child was lying. The face was normal, and the child was able to suck quite well.

Under observation the movements of the patient continued excessively feeble, and the asthenia persisted. It was noted by the parents that the child was able to make movements of its limbs in the bath that were impossible out of the water.

It succumbed to broncho-pneumonia when six months old.

CLINICAL ABSTRACT OF SORGENTE'S FAMILIAL CASES, WITH A CLINICAL AND PATHOLOGICAL REPORT OF ANOTHER CASE OF THE SAME GROUP.

Case 26 (Beevor[1] [3]).—Male, aged 5 weeks. He was the youngest of eight children, of whom the first, second, fourth and eighth were similarly affected. The paralysis had become noticeable in these children at the following times after birth: in the first child at four weeks, in the second child at six months, in the fourth child at six weeks, and in the present patient it was obvious at birth. The other children of the family were aged respectively 14, 9, 8 and 1 year and 9 months; they were all healthy.

The mother had had good health during the pregnancy, but she had never felt any fœtal movements with this child. The child was born at full term and weighed 15 lb., the birth was easy and natural. The infant was black from asphyxia when born and was at once noticed to be paralysed.

The child was well nourished and it was lively and contented There was absolute flaccid palsy of all the voluntary muscles of the body with the exception of the muscles of the face and neck and the diaphragm; the intercostals were completely inactive. Very slight and feeble movements of the fingers of the left hand were possible. Faradic excitability in the affected muscles was completely lost, and to galvanism A.C.C. was greater than K.C.C. The special senses and cranial nerves were normal and no bulbar symptoms were present, the child being able to suck powerfully. There was complete loss of sensibility to all forms of stimulation over the whole of the body and limbs, reaching as high as the upper limit of the fourth cervical segment; above this limit sensibility appeared to be normal. Reflex action of the bladder was performed normally and the anus was not patulous.

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[1] This case was published by Dr. Beevor in *Brain*, 1902.

The knee-jerks and the other deep reflexes were absent, but the superficial reflexes were present, the plantars showing a slight extensor response. Under observation the muscles wasted rapidly, the respiration became increasingly embarrassed, and the child died of respiratory failure at the age of eight weeks.

The pathological examination was conducted by Dr. F. E. Batten. The external appearance of the nervous organs was normal. The tissues were examined by the Marchi, Weigert-Pal, van Gieson and the Stroebe methods. The brain, cerebellum, brain-stem and the cranial nerve nuclei were normal. There was intense atrophy of the anterior horn cells throughout the spinal cord less marked in the fourth cervical segment. There was intense recent degeneration of the fibres of the posterior columns throughout their extent, but the posterior roots were not degenerated. There was great atrophy of the fibres of all the affected muscles.

Case 27 (Sorgente [24]).—Male, aged 27 days. Natural birth at full term. No quickening during pregnancy. Breast fed. From the day of its birth unable to move arms or legs. Well nourished and developed; plump legs, with complete flaccidity of the muscles. Little voluntary movement of head, respiration entirely abdominal, with indrawing of lower thoracic margin during inspiration. No alteration in sensation. No voluntary movement of limbs in response to painful stimuli. Absence of cutaneous and deep reflexes; no reaction in muscles of legs to either faradic or galvanic current; minimal reaction in arms. During ten days treatment in hospital, signs of movement in arms, and breathing became more of costo-abdominal type. Death three days later from bronchitis. No autopsy obtained. Five hours before death, general convulsions, with rotation of the eyes, shaking of head, and tonico-clonic movements of all the limbs.

Case 28 (Sorgente [24]).—Sixteen months later 5-day-old female child of same parents was brought to hospital. Mother ill and weak during pregnancy, and had not observed quickening. Child well developed; flaccid paralysis of legs, flaccidity of arms, but some slight movements in them. Otherwise, clinical picture as with previous child. Death after 15 days, preceded during twenty-four hours by general convulsions.

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THE STRUCTURE AND FUNCTIONS OF THE CEREBELLUM EXAMINED BY A NEW METHOD.

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PART I.—METHODS.

I.—INTRODUCTION.
II.—RECTILINEAR TOPOGRAPHY.
III.—STEREOTAXIC INSTRUMENT.
IV.—ELECTROLYSIS.
V.—EXCITATION.

I.—INTRODUCTION.

THE methods and experiments described in the following pages are the direct outcome of an investigation into the anatomical relations of the cortex of the cerebellum to its nuclei and peduncles, and to the rest of the brain and spinal cord. An account of that research was published in *Brain* in the spring of 1905.

When we began that work (1903) the view had been gaining ground that there was no direct path from the cortex of the cerebellum to the peduncles or to the spinal cord, and had been advanced by distinguished observers, especially Ferrier and Turner, Risien Russell and Thomas, who expressed themselves more or less definitely in favour of this opinion, and supported it with observations furnished by their own experiments. But although the evidence adduced established a strong probability we did not consider that it amounted to proof, as the conclusions were founded on lesions involving both cortex and nuclei, or complicated with injuries to other parts. Nor were all the conclusions of the authors absolutely definite. Marchi originally described a direct descending path in the spinal cord derived from the cerebellum. Ramon y Cajal spoke of this tract in a rather ambiguous way, leaving the reader in some doubt whether he recognized the tract himself or was merely quoting Marchi by calling it the *via descendente*. Ramon y Cajal also described some fibres passing from the cerebellar cortex to the superior peduncle.

Thomas in his classical work ("Le Cervelet"), though generally supporting the view that no direct cerebello-spinal path existed, yet gave illustrations of a case of cerebellar lesion exhibiting degenerated (tecto-spinal) fibres in the spinal cord; and though he stated that there was an accidental lesion of the posterior colliculus which might have produced degeneration of such a spinal tract, Thomas was of opinion that these fibres were derived from the cerebellum.

The later illustrations of Probst all showed more or less injury to the nuclei, and though he made the deduction that the amount of degeneration seen in the peduncles or beyond them was proportional to the amount of injury to the nuclei, and was therefore derived entirely from them, the lesions were not sufficiently defined to justify these conclusions.

Considering this position of the subject was unsatisfactory, and that besides the anatomical question the much broader one of the respective functions of the cerebellar cortex and nuclei was as yet wholly undetermined, we resolved to try and find some more conclusive evidence by which to decide these points. The failure of previous experiments to afford absolute proof appeared to be due in all cases to the fact that the lesions had not been sufficiently limited, and it seemed most probable that if special precautions were observed to avoid this defect in a series of cortical lesions, following the resulting degenerations by Marchi's method, definite information regarding the course and destination of the cortical fibres would be afforded.

The results justified these anticipations. Small lesions of the cortex were made by one of us (V. H.) in anæsthetized animals—monkeys, dogs and cats. In thirteen cases the cerebellar nuclei were absolutely untouched, the lesions being strictly confined to the cortex; and of these cases, though there were abundant well-stained fine fibres passing to the adjacent folia (arcuates) and to the intrinsic nuclei, none showed degenerated fibres in any of the peduncles or in the spinal cord; this evidence appeared to us conclusive.

We did not think it necessary to perform any more experiments for the purpose of accumulating evidence on this question, but accepting the data as correct have endeavoured to follow up the indications they afforded. This view was corroborated by the appearance (after the publication of our paper) of an important research by van Gehuchten, who quite independently came to the same conclusion from experiments on another species of animal, viz., the rabbit.

As a result of these experiments we were led to the conclusion that the cerebellar cortex is essentially a recipient organ (Edinger); its efferent fibres passing to neighbouring folia and to the cerebellar nuclei, the latter being regarded as stations interposed between the efferent cortical fibres and the rest of the nervous system. Collectively, therefore, these nuclei might be considered the focus of cerebellar activity, and regarding this as the standpoint from which further investigations of their structure and function must proceed, we resolved upon a systematic inquiry into the function of the cerebellar cortex and nuclei respectively.

On making a general survey of the subject before us, and considering the most promising methods of research, we were confronted with the following preliminary difficulty: The nuclei of the cerebellum in monkeys, dogs, and cats are small, deeply situated, and not very accessible for excitation experiments, while it is evident that to get results of any value by Marchi's degeneration method, lesions must be precisely limited to the nuclei, or, if possible, to parts of them, and that such lesions must not only be accurately localized but also produced without noteworthy injury to other structures, for we had already observed the difficulties and confusion which such complications have introduced into the discussion of the subject. An essential preliminary, therefore, to further progress was to find some method which would satisfy these conditions, viz., a means of producing lesions of the cerebellar nuclei which should be accurate in position, limited to any desired degree in extent, and involving as little injury as possible to other structures (*see* fig. 20A, p. 98). Neither puncture with a small knife, nor galvano-cautery, nor the injection of acids or other fluids appeared to us to fulfil these conditions adequately, and we therefore discarded them. At this time (1904) we were unaware of the experiments of Sellier and Verger (see p. 86), in which insulated needles were used for the production of electrolytic lesions in the brain, and we arrived independently at the same point after a number of preliminary experiments which will be referred to presently. At first, although the application of an electrical current to the nuclei by means of needles insulated to within a short distance of their points appeared most likely to serve our purpose, we were doubtful whether it would be better to employ two insulated needles and a current of high tension, thus obtaining destruction by sparks, or to use a single needle and a surface electrode with faradism or electrolysis; it is sufficient to say here we soon abandoned both the spark and faradism. The former was too violent and difficult to regulate, and the latter set up vigorous convulsive movements which are too severe to allow of the application being maintained long enough to produce an effective lesion; but the electrolytic method appeared promising from the first, and after several years experience we regard it as satisfactory. The conditions under which a lesion should be made, and which we have enumerated already, are not very exacting, but, such as they are, electrolysis fulfils them in a way which leaves little to be desired. As we shall explain more fully later, electrolytic lesions of the brain, especially anodal ones, are quickly and easily produced with very slight injury to any other parts; their size can be accurately regulated, their form depends on the nature of the electrode, they are precisely defined, and the necrosed tissue passes in all directions almost abruptly into the uninjured tissues, which do not appear to be even temporarily affected by the lesion; while, finally, with the stereotaxic instrument we are going to describe, we are able to direct a protected stimulating and electrolytic needle to any desired part of the brain with very fair accuracy. All these particulars are included in the method which in this paper we propose to explain fully before giving in a separate communication the results we have obtained with it on the cerebellum. We shall begin with an account of our method of cranio-encephalic topography and measurement, followed by a brief discussion of the subject of electrolysis of central nerve tissue, including the physical and chemical characters and microscopical structure of the lesions, the different effects of anode and cathode, concluding with a discussion of the methods of electrical stimulation we have employed on the cerebellum. In a second communication we shall describe the results obtained by these methods on the structure and functions of the various parts of the cerebellum and cognate centres; this will include an account of the anatomical position of a great number of lesions, the course of the degenerated fibres and tracts they have produced, and an analysis of the functional changes and clinical symptoms which have been associated with them.

A preliminary account of our methods and of the stereotaxic instrument was published by one of us (V. H.) at the meeting of the British Medical Association at Toronto, August, 1906.

II.—RECTILINEAR CRANIO-ENCEPHALIC TOPOGRAPHY.

The first requirement in a research of this kind is the establishment of the relations existing between the exterior of the head in animals and its encephalic contents, especially in the monkey, but also in orders as far apart as the carnivora, insectivora, and birds.

As yet relatively little information exists on this question, although it is of fundamental importance in anatomy.

For the higher vertebrates the valuable drawings (especially fig. 9, p. 69) in the text-book by Flatau and Jacobson [3] are useful indications, but for our purpose it was necessary to have not only a precise knowledge of the proportionate relations, but a means of reaching any definite spot in the encephalon, and we were therefore compelled to begin *de novo*, and, as will be seen directly, have adopted a method in which the objective is determined by measurement from a zero inside the encephalon, and not by the usual projection on the exterior and measurement from it.

On the question of correct technique in making cutting lesions in the central nervous system, the most important communication that has recently appeared is that by Wilhelm Trendelenburg [24]. After quoting the well-known methods of Longet, Nawrocki, Dittmer, Cyon, Woroschiloff, Probst, and Corona he points out that it is possible to devise an apparatus which consists of two parts: first, a model in brass foil of a sagittal section of that portion of the nervous system in which it is desired to make a lesion; and, second, a knife ingeniously devised of stout steel wire, so that it is possible to guide its one extremity by a hole in the brass plate (such hole representing the desired lesion), while the other extremity enters the brain. It will be understood that the model is fixed above the brain in which the lesion is to be made, that the knife is made to follow the outline in the model, and that its parallel movements and adjustment are cleverly obtained by a lazy-tongs arrangement, for movements in two planes, frontal and horizontal, that in the vertical plane being provided by sliding up and down an upright. It will be seen, of course, that this *myelotom*, as Trendelenburg names it, does not fulfil the conditions we feel must be satisfied. It is, however, a great advance on the cannulæ and hook-like stilettes, devised by Veyssière and subsequently employed by Bechterew, Probst, and other workers, since it includes an accurate control of the cutting point during the whole operation.

To meet our immediate necessities, and at the same time to provide a plan of general application to the whole encephalon, a method of rectilinear topography and a stereotaxic instrument for applying it to direct an insulated needle to any desired point in the brain for excitation or electrolysis were devised by one of us (R. H. C.), and we have employed them for the last three years for the study of the structure and functions of the cerebrum and cerebellum in various animals.

Topographical Data and Measurements.

The difficulty of arriving at the precise localization of a point in the deep structures of the brain is due to several causes which have been generally recognized but not hitherto satisfactorily met. The first and most obvious one is that of making accurate measurements of the curved surface of an irregular sphere, like the head, especially when there are few constant and trustworthy features to serve as fixed points, while of these the precise definition is obscured, and their value more or less impaired by the mobile integument and muscles which cover the cranium. The initial difficulties are much enhanced when the ultimate objective to be localized is not on the surface, but deeply situated and probably at an uncertain distance within the cavity of the skull, and when allowance must be made for variations of thickness of the bones and their coverings, and of the size, shape, and symmetry of the structures concerned. We find, however, that a practicable and, on the whole, satisfactory solution of this problem may be attained by dividing the cranium into eight segments, by three section planes at right angles to each other, *e.g.*, sagittal, horizontal, and frontal. As a result of these sections, each segment presents the three internal surfaces of a cube, and every point in it can be identified by rectilinear measurements from those surfaces or section planes, *i.e.*, from their *internal* boundaries. By this means the irregular curved surface, which corresponds to the three outer sides of the cube, is not involved in any way and needs no further consideration.

In short, instead of employing the usual method of endeavouring to project the detailed structure of the interior of the encephalon on to the surface of the head, we measure the position of the deep parts of the brain by their relation to three section planes.

The advantage of applying this principle, which, so far as we know, is new in the topography of the brain, to the localization of structural detail for the identification and record of lesions, and for the mechanical direction of an insulated needle for excitation or electrolysis, is obvious, and its utility will become more evident as we proceed to consider the details of its practical application.

The essential points of this principle may be briefly summarized as follow:—

(1) Any irregular solid may be divided by three section planes in three dimensions into eight segments, in each of which the three internal surfaces are those of a cube.

(2) In any solid body a constant point which can be measured from plane surfaces, representing the three dimensions of a cube, can be identified by three perpendiculars of correct length dependent from those surfaces, and it is the only point where those perpendiculars can meet.

(3) A needle may be substituted for any of these perpendiculars, and in order that it may be directed mechanically to any required point in any of these rectilinear segments, an instrument is necessary which will introduce it in a direction perpendicular to one surface, and therefore parallel to the other two, to any required distance from the first surface, any required distance from the others, *i.e.*, the needle must have a regulated movement in three dimensions.

The Determination of the Three Section Planes of the Head.

These principles are applicable to the identification of any point within the brain of a living animal and to the direction of a needle to it, provided that the conditions as defined are fulfilled. Now it is obviously practicable to divide the cranium by three section planes, which in the living animal are imaginary (definition 1). We can construct an instrument which meets the requirements of definition 3. The only difficulty lies in the determination of "constant points which can be measured from plane surfaces representing the three dimensions of a cube" (definition 2). This measurement cannot be effected in the living animal; the distance of a selected point must therefore be known from the measurement of other heads, and can be trusted only so far as these data are constant. Hence it is essential to find a method of determining section planes, which are themselves constant and can be proved by experiment to have a constant relation to any selected point within the brain.

The simplest method of selecting section planes of the cranium would be to bisect its longest diameters in three dimensions by planes perpendicular to them. This is not practicable in the case of the vertical diameter because of the structures of the neck, and in order to determine the frontal and median sagittal planes, by bisecting the longitudinal and transverse diameters of the cranium, we must first define those diameters. But there are no landmarks on the surface of the skull beneath the integuments which are sufficiently clear and precise to determine an accurate longitudinal diameter, though for transverse diameters we can utilise such prominent features as the eye and ear. The simplest method, therefore, is to begin with these structures and adopt the centre of the external auditory meatus and the centre of the lower margin of the orbit on both sides for the definition of the horizontal plane, or a basal plane to which the horizontal section plane is parallel but about 10 mm. nearer the vertex.

Beginning with this basal plane we can define the frontal section plane as perpendicular to the horizontal and passing through the centres of both meatus, and the sagittal section plane as bisecting the cranium perpendicular to the other two (section planes).

It will be seen (p. 63) that this order will be followed in the application of Clarke's stereotaxic instrument. The horizontal frame is adjusted and fixed to the four points (eyes and ears) of the basal plane. By the same process the frontal zero plane is brought into place perpendicular to the horizontal plane and cutting the centres of both meatus, and the sagittal zero plane, perpendicular to the other two, is made to correspond with the median sagittal plane of the cranium by four graduated lateral clamps.

We consider the above are the most satisfactory section planes; we have verified them by the methods of drilling and passing ivory needles and making frozen sections as described elsewhere (p. 59), and, as far as our experience goes, their relations to the most important structures of the brain are constant, with such corrections for size and symmetry as are necessary, and also quite practicable (*vide* p. 82).

Various anatomical features, such as sutures of the cranial and facial bones and surface markings of the brain, will be found useful for verification of the accuracy of adjustment of the instrument.

It will be noticed that the centre of the external auditory meatus corresponds to the auricular point of anatomists, and the basal plane differs very slightly from the Frankfort-Munich plane, the latter being determined by the upper margins instead of the centres of the external auditory meatus.

Reference has been made to the situation of the zero horizontal section plane being about 10 mm. above the basal plane; the object of this is to make it more central. The advantage of making the section planes as central as possible is not only that it brings them into closer relation with the most important structures of the brain, but as all measurements are made in both directions from each of the three section planes which count as zero, the margin of error in measurement is reduced.

The precise position of the zero horizontal section plane is therefore a level determined by what has been found convenient in practice in the animals we have used. Thus in the average *Macacus rhesus* the distance from the centre of the auditory meatus to the vertex, perpendicular to the base line, is 40 mm.; in the cat it is about 30 mm.; in the hedgehog about 20 mm. But whilst in the *Macacus rhesus* the inter-aural line (that is a line passing from the centre of one meatus to the other) passes through the pons, in the cat it touches the inferior surface of the pons, while in the hedgehog it is still further ventral and lies in the basi-occipital bone. This has suggested to us that the zero-horizontal section plane in the *Rhesus* should be placed at one-fourth of the distance from the meatus to the vertex, that is 10 mm. on the average above the basal plane (passing through the auricular point in the meatus and the orbital border). In the cat one-third of the distance from the meatus to the vertex, and in the hedgehog one-half the distance, places the zero horizontal plane at proportionately the same region of the encephalon. In all these animals the horizontal section plane will then be about 10 mm. above the base line and convenient for measurements above and below it. For these animals, therefore, we have adopted this arrangement, but possibly future investigators employing different animals may find other proportions more convenient.

The Subdivision of the Encephalic Segments into Lamellæ and Cubic Millimetres.

As already described, the whole encephalon is divided by the three zero section planes into eight segments, which are, we designate, right and left frontal, occipital, temporal and cerebellar, and each segment of the encephalon presents on its inner aspect three rectilinear surfaces corresponding to the three section planes—sagittal, frontal, and horizontal. On frozen sections of an animal's head, the preparation of which will be presently described, the distance from any point of these three surfaces of any segment can be measured and then, for an actual experiment, by means of the stereotaxic instrument, which is adjusted by these indications and carries an excitation and electrolyzing needle travelling on graduated guides in each of the three planes, it is easy to direct the latter to a similar point in an intact head. The identification of the desired point and the direction of the needle are made practicable by finally subdividing the segments into cubic millimetres as follows: Each segment is theoretically subdivided into slices or lamellæ 1 mm. thick in each plane, and each lamella is divided by lines parallel to the other two planes into millimetres. For the study of the topographical detail and structure of each lamella working "charts" are made by cutting frozen heads in a special instrument into lamellæ in all three planes. To secure the identification of the section planes perpendicular to the lamellæ thus prepared fine ivory knitting needles are previously introduced by a drill. For instance, for lamellæ in sagittal sections, two fine ivory rods are passed transversely from the auditory meatus and orbital margin of one side to the corresponding points on the other; each sagittal lamella therefore shows a section of the two ivory needles, a line joining which is our base line. A glass plate (fig. 1), divided by ruled lines into square millimetres and by two bold lines crossing in the middle into four parts, is then placed on the surface of the lamella, and with the aid of the centres of the ivory points the glass plate is adjusted so that the two bold lines coincide with the frontal and horizontal lines or section planes. The distance of any point in the lamella from these lines can then be directly read off, and as the number of the lamella indicates the number of millimetres from the median

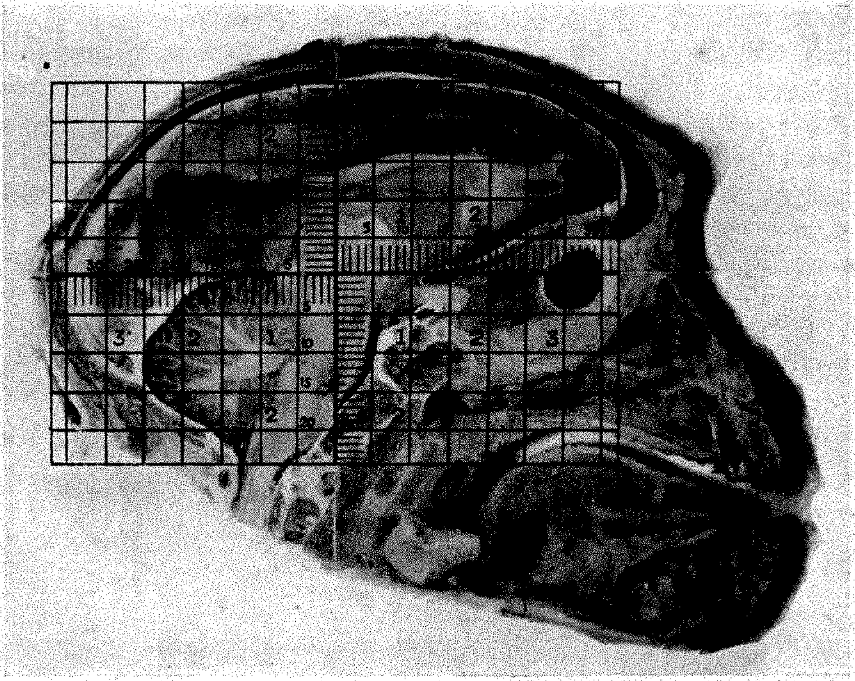

FIG. 1.

Sagittal section of frozen head of Rhesus, and millimetre glass plate.

section plane, the exact[1] distance of the selected point from the three inner surfaces of the segment in which it lies is known. Though it is useful to have several series of lamellar sections cut in all three planes, it is best to make records and references as far as possible to one plane only, and the sagittal plane is the most convenient for this purpose.[2] Further advantages of such limitation are: much less confusion and greater brevity of reference. If it is understood that all lamellæ not otherwise specified are situated in the sagittal plane, the word sagittal is superfluous. Lamella vi. then signifies a lamella in the sagittal plane 6 mm. from the median sagittal plane. It is also convenient to indicate the ordinates, *i.e.*, distances above or below the zero horizontal plane in the ruled plate, and so in the lamellæ by letters of the alphabet, while the abscissæ or distances in front or behind the zero frontal (inter-aural) plane are denoted by numerals. If the sagittal plane is adhered to, one soon learns that letters refer to millimetres above and below the horizontal line and numerals to millimetres before and behind the frontal line. At first the use of letters to indicate numbers is rather confusing, but after a little practice one remembers the numbers the letters correspond to without much difficulty. The advantage of having a short and easily recognized reference to any cubic millimetre will be appreciated in practice. Thus a rhesus' brain contains about 200,000 c.mm., and yet by the method described any given cubic millimetre can be identified by a reference as short as the following: *Left frontal segment, lamella* v. *J.* 6. Such a statement refers to a cubic millimetre in the left frontal segment 5 mm. to the left of the median sagittal plane, 10 mm. above the zero horizontal plane, and 6 mm. in advance of the inter-aural or zero frontal plane. With that reference it is easy to select from the frozen sagittal sections lamella v., and by applying the ruled glass plate with the help of the points marked by the ivory, so that the cross coincides with the frontal and horizontal lines, to identify the deep structures which correspond to J. 6.

This sketch of the principles of what may be called rectilinear topography may serve to explain the measures required for its application, which must now be rather more fully described.

Working "charts."—These consist of a series of sections of the

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[1] For corrections due to size, &c., see p. 82.

[2] Probably, too, most investigators visualize the encephalon sagittally, *i.e.*, as a lateral view, the head being in the anatomical position with the visual axes horizontal, although it has unfortunately been the stereotyped custom to make the large majority of anatomical researches by sections in the frontal plane only.

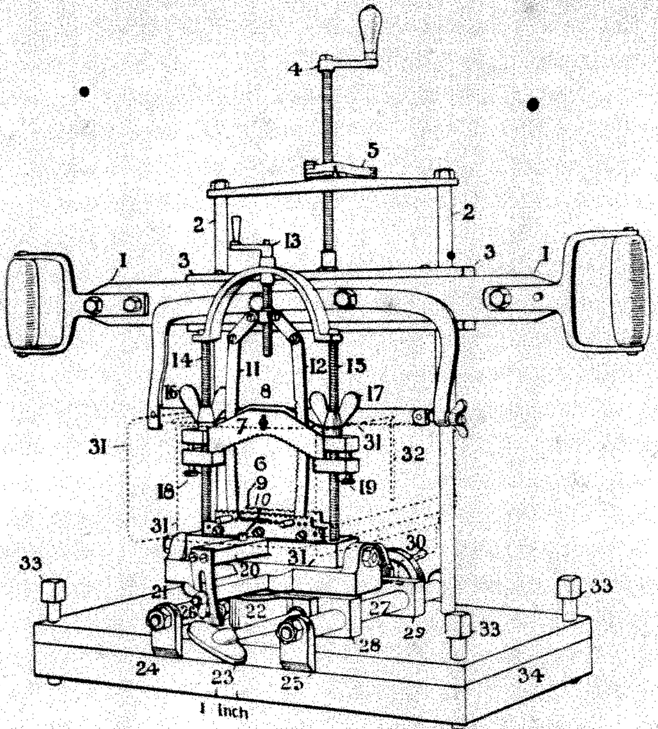

FIG. 2.

Clarke's Saw for cutting sections of frozen heads 1 mm. or 2 mm. thick.

1 Hack saw working on horizontal and vertical guides.
2 Vertical guides for saw.
3 Horizontal guide for saw.
4 Screw for raising and lowering saw.
5 Grip with spring catch, in which screw 4 works.
6 Placed in centre of head vice.
7 Posterior blade of upper jaws of head vice.
8 Anterior blade of upper jaws of head vice.
9 10 Anterior and posterior lower jaws of head vice.
11 12 Vertical jaws of head vice.
13 Screw for approximating vertical jaws of head vice.
14 15 Screw guides for upper jaws of head vice.
16 17 Fly nuts for depressing upper jaws of head vice on screw guides (14, 15).
18 19 Screw for adjusting upper jaws of head vice.
20 Rocking adjustment of head vice.
21 Fly nut for clamping rocking adjustment (20).
22 Rotatory adjustment of head vice.
23 Screw for clamping rotatory adjustment (22).
24 25 Fixed brackets supporting guides of travelling stage of vice.
27 Right guide of travelling stage of vice.
28 29 Travelling stage of head vice.
30 Graduated wheel for moving travelling stage of vice on guides—One complete turn = 2 mm. movement of stage.
31 Zinc tray (shown by dotted lines) to confine CO^2 snow.
32 Dotted lines show gap in sliding side of tray for saw.
33 Levelling screws of foot-plate.
34 Foot-plate.

frozen head of an animal of the same species, and as nearly as possible of the same size as that which is to be used for the experiment. These sections are cut with a saw in a special instrument (Clarke) (*see* fig. 2) 2 mm. thick, parallel to one of the section planes, and mounted in glycerine jelly between glass plates. Each section shows two lamellæ, one surface of each lamella being visible under the glass plate which covers it. The lamellæ are measured and numbered from the section plane to which they are parallel. Thus they will be right and left sagittal, superior and inferior horizontal, anterior and posterior frontal lamellæ in their respective planes, and the number of any lamella indicates the number of millimetres from the zero section plane to its distal surface, *i.e.*, lamella i. lies between the section plane and a section 1 mm. from it. It is convenient to have a series of lamellæ in each plane, but the sagittal is most important, since we make, as already stated, all records and references in it unless otherwise indicated.

Preparation of the head.—Heads of different sizes are injected with warm 10 per cent. formalin, or equal parts of this and Müller's fluid. If not injected before the vessels have time to contract, the injection should be put off for several hours till the contraction of the vessels has begun to pass off; only moderate pressure should be employed, 0·5 to 1 metre of water is sufficient. After the injection is completed two or three holes are trephined in the skull, and the head is suspended in equal parts of 10 per cent. formalin solution and Müller's fluid of double strength; it is ready to cut in a few days.

Drilling.—It has been explained already that the directions of the section planes are identified by passing two ivory knitting needles (size No. 13 or 14) in one of the section planes perpendicular to that in which the sections are made. For this purpose, and for the attachment of the stereotaxic apparatus later, it is necessary to obtain an accurate centreing of the external auditory meatus, which is accomplished as follows. Fig. 3 represents the drill, which is passed through the auditory meatus in the following manner: The same ear plugs which are used for subsequently adjusting the head in the stereotaxic instrument are employed for the drilling, being bored for this purpose. These ear plugs are made by modelling from casts of the external auditory meatus conical plugs of different sizes so as to fit different meatus, and bent 3 mm. or 4 mm. from the base at an angle of about 20°. The floor of the meatus in the rhesus and in most animals forms a slight elevation a little internal to the external orifice and, in the rhesus, is then directed downwards and forwards. The bend in the conical plug divides it into two

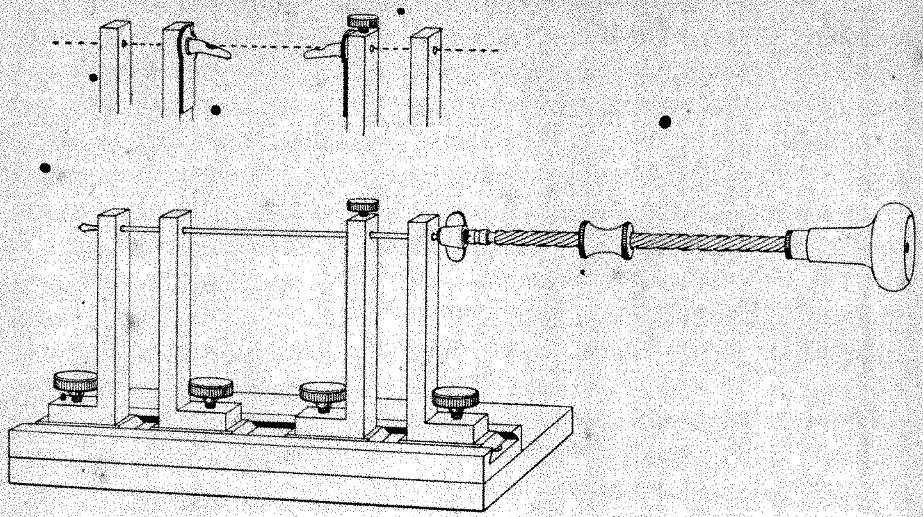

FIG. 3.

Clarke's drilling instrument.—For defining the relation of external to internal structures and determining section planes by means of ivory needles passed through corresponding points on opposite sides of the cranium and cut in frozen sections.

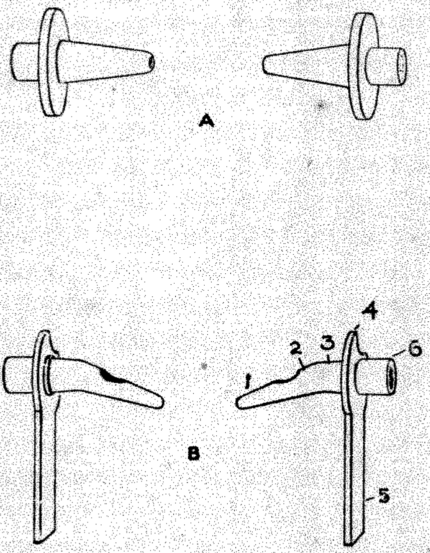

FIG. 4.

Ear Plugs.

1, cone; 2, angle; 3, barrel; 4, disk; 5, flange; 6, funnel.

parts, an inner conical part (the cone) and a short outer cylinder, the barrel (fig. 4). A disc and flange are attached 3 mm. or 4 mm. from the bend, and the barrel is continued and expands slightly to a few millimetres beyond the external surface of the disk to form the funnel (fig. 4), which admits the cylindrical end of the aural pivots in the stereotaxic instrument or the nipples of the drilling apparatus. For passing the ivory needle and marking the inter-aural line, the ear plugs are introduced into the meatus and the two inner uprights of the drilling apparatus (*see* fig. 3) are brought together in the slide till the nipples enter the funnels of the ear plugs; they are then pushed home and clamped, the head being supported by the ear plugs and nipples on the two inner uprights. The drill is passed first on one side and then on the other through the perforation in the two uprights, by which accuracy of direction is secured, the petrous bone being drilled through on each side to the middle line; then a steel needle is passed the whole distance from one outside upright to the other (fig. 3), and finally the ivory needle. For drilling between the malar margins of the orbit the points are marked on each side, then the head is fixed in a clamp between the two uprights and drilled from each side as before, and the ivory needle can then be passed in the place of the drill. The points at which the drills are entered for different section planes should be marked by putting the head in the stereotaxic instrument, and it is desirable to do this and to drill when the head has been but recently fixed (*i.e.*, before it has been rigidly hardened), so that the soft parts of the auditory meatus are practically in a natural condition.

Cutting.—The instrument for cutting frozen sections has been altered from time to time, but its general construction can be seen in the illustration (fig. 2). It consists of a hack-saw working in vertical (2) and horizontal guides (3), the saw being raised or lowered by a screw which can be released by a catch (4). The head is carried on a travelling stage which is moved in guides at right angles to the saw by a graduated wheel (30), one complete turn of which moves the block 2 mm. The stage (28) carries a head vice (6) on a plate with rotating and rocking adjustments (20-22) by which the head can be adjusted in two dimensions after it is fixed in the clamp. Two zinc plates (31) are fixed to the front and back of the travelling stage (28), and two lateral ones, attached by a sliding movement to its sides (32), confine the frozen CO_2 which is used to freeze the head, and the lateral plates have a gap (32) directly beneath the saw in which it descends. Some of the frozen snow escapes through these gaps, but not much. The head can be gripped in the clamp by one side, by the face, or by the base for sections in the sagittal, frontal, or horizontal planes. Having been secured it is next aligned by the adjustable plate guided by plummets suspended from the ends of the saw and by the surface markings on the head. A superficial saw cut is made to begin with in the median section plane, *i.e.*, for sagittal sections in the median sagittal line, and the distance from this line to the limit of the furthest sections to be cut is measured and marked. The head is then packed with frozen CO_2 moistened with ether. Freezing usually takes about half an hour. If frozen too hard the sections are too brittle and apt to break. If too soft they are apt to bruise and tear, but the right degree is soon learned with a little practice. When freezing is apparently complete the screw is worked till the position chosen for the first saw cut is brought directly under the saw and the first slice removed. If the surface, which can now be seen, is properly frozen its distance from the median section plane is measured with a depth gauge, the plate of which is applied to the cut surface, while the sliding bar of the gauge terminates in a knife edge which fits into the superficial saw cut previously mentioned, and gives the distance in millimetres of the cut surface from the section plane, that is to say, the number of the lamella which that surface represents. A glass plate is then smeared with gum and applied to the cut surface, to which it immediately freezes and protects the next section while it is being cut. The block is now moved forwards 3 mm. by the screws, so that the saw cut and *débris* being equivalent to 1 mm., the section will be 2 mm. thick. As soon as it is sawn through it is placed in a dish of water, the number of the section and the distance of its surface being written on the glass plate. The same operation is repeated till all the sections are cut. They must then be carefully cleaned from the saw dust and *débris* in water, and left for a couple of days in equal parts of glycerine and water to dissolve out some of the formalin and chromates, as these have a tanning effect on the gelatine of the glycerine jelly which is apt to be troublesome. The sections are permanently mounted in glycerine jelly.

It is right to mention that there is a difficulty in mounting in glycerine jelly owing to the shrinking of gelatine produced by formalin and chromates, even after soaking the sections in glycerine and water. The most convenient way of mounting them is to make cells with glass plates large enough to include the section, and walls of square glass rods 3 mm. or 4 mm. diameter. When dry the cell is filled with warm glycerine jelly, and the section introduced with care to avoid bubbles. After a time the gelatine shrinks, air may find its way in, and occasionally the shrinkage breaks the glass plates and the sections have to be remounted. The number of the lamella should always be immediately written on the glass covering the section with enamel paint.

General Conclusions on the Topographical Relations of the Encephalon in the Macacus rhesus.

From a large series of measurements of heads of *Macacus rhesus* and in a few cases of *Macacus cynomologus* we have been able to construct a

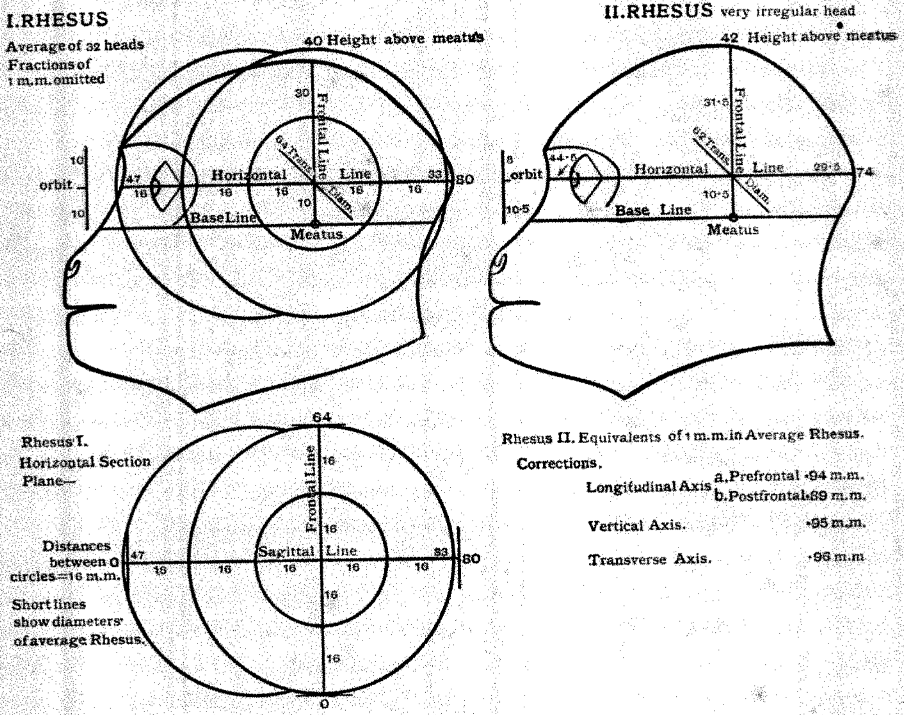

FIG. 5

Drawing of sagittal sections of heads of two Rhesus. I. Average size, and II. an irregular head. To illustrate measurements.

scale of averages for the former animal, and before describing the stereotaxic instrument we use for excitation and electrolysis we may perhaps with advantage first recount the general dimensions of the head in a *Macacus rhesus*, whose total body (head and trunk) length is about 320 mm. This being the commonest and most convenient size, we have as far as possible employed it only.

In fig. 5 is a reduced outline from a drawing on millimetre ruled paper showing the dimensions of a rhesus' head taken from an average of between thirty and forty specimens (avoiding fractions of 1 mm.). The base line passes through the centre of the lower margin of the orbit and the centre of the auditory meatus. Its length longitudinally is not used for calculation. Perpendicular to the base line is the frontal line, representing the (inter-aural) frontal section plane and erected from the centre of the meatus to the vertex; in the average rhesus it is 40 mm. in length. The greatest vertical diameter of the orbit is next taken and found to be 20 mm. on the average, or exactly half the height of the frontal line. On this point the constancy of the dimensions of the orbit in *Macacus rhesus* deserves some attention in view of opinions prevailing among craniologists on the value of orbital measurements. It is not a little remarkable that in examples of this species of monkey about 320 mm. long, the greatest vertical height of the orbit should rarely vary more than 0·5 mm., or at the outside 1 mm. from a total (greatest depth) of 20 mm., and in the large majority of cases not at all.

Further as regards symmetry any difference between the two orbits when present (and this is extremely rare) never exceeds 0·5 mm. It follows, therefore, that the determination of the lowest point in the lower margin of the orbit gives very satisfactorily the anterior point for the construction of the base line. To obtain the next convenient dimension, namely, the horizontal zero section plane, it will be seen that half the orbital height and one-fourth of the average frontal line are in both cases 10 mm. on the average. At this level, therefore, viz., one-fourth of the frontal line, we draw parallel to the base line the horizontal line representing the zero horizontal section plane, which extends from about the nasion to the occiput. Level in front with a line joining the two inner canthi, from nose to inter-aural plane it measures 47 mm. on an average, and from this plane to occiput 33 mm., making an average total length of 80 mm. Finally the greatest transverse diameter of the frontal plane is taken with callipers and found to be maximal at about the level of the horizontal plane and 64 mm. on the average. The point where these section planes meet in the median plane is zero, and all measurements are reckoned from it, as we have already indicated on p. 50. Two interesting points may be noticed in the above measurements: one is that the frontal line (the median section of the inter-aural plane) is exactly double the vertical diameter of the orbit, the other is the relation of the number 16 to several of the average measurements; thus it is one-fifth of the longitudinal and one-fourth of the transverse diameter in the horizontal plane. In some animals with the same total longitudinal measurements the frontal line is 1 mm. further back, making the division of the longitudinal diameter 48 and 32 instead of 47 and 33 mm., these being also multiples of 16 in the proportion of 3 : 2, and in the horizontal section plane itself the relations of this number are still more striking, for the section of the skull at this level is almost exactly represented by one circle with a radius of 32 mm. and its centre at zero and half a circle with the same radius at a point 16 mm. further forward on the median sagittal line. Probably the average of a still larger number of (320 mm.) rhesus monkeys will differ a little from this, but the relative proportions are not likely to alter much, and accumulated experience proves that the above-stated figures will continue to be accurate guides.

III.—DESCRIPTION OF CLARKE'S STEREOSCOPIC INSTRUMENT EMPLOYED FOR EXCITATION AND ELECTROLYSIS.

The application of the foregoing facts to our experimental investigations has been effected by an instrument, the general plan of which will be most easily obtained by an examination of the illustrations. It would be very tedious to follow a minute description of every screw and detail, and the purport of any of these can be ascertained by referring to the figures and letterpress, consequently no more will be attempted in the text than a short explanation of the essential features and their direct application to the animal's head.

The foundation of the stereotaxic instrument is a rigid quadrilateral rectangular frame (the "horizontal frame") the ends of which (the "nasal" and "occipital" bars) can be approximated by joints which slide on the lateral bars. The lower border of this frame, which is in the same plane on all four sides, is adjusted so as to correspond accurately with the zero horizontal section plane of the head and is fixed in this position on the skull by four lateral screw points all furnished with millimetre scales, so that in addition to fixing the frame they make the median sagittal line of the frame coincide with the sagittal section plane of the head. It will be seen directly that the horizontal pivot bars articulating with the ear plugs in the auditory meatus, on which the topographical adjustment of the horizontal frame primarily depends, also indicate the points of incidence of the perpendiculars to the horizontal

[1] The instruments were made by Messrs. Swift and Son, Tottenham Court Road.

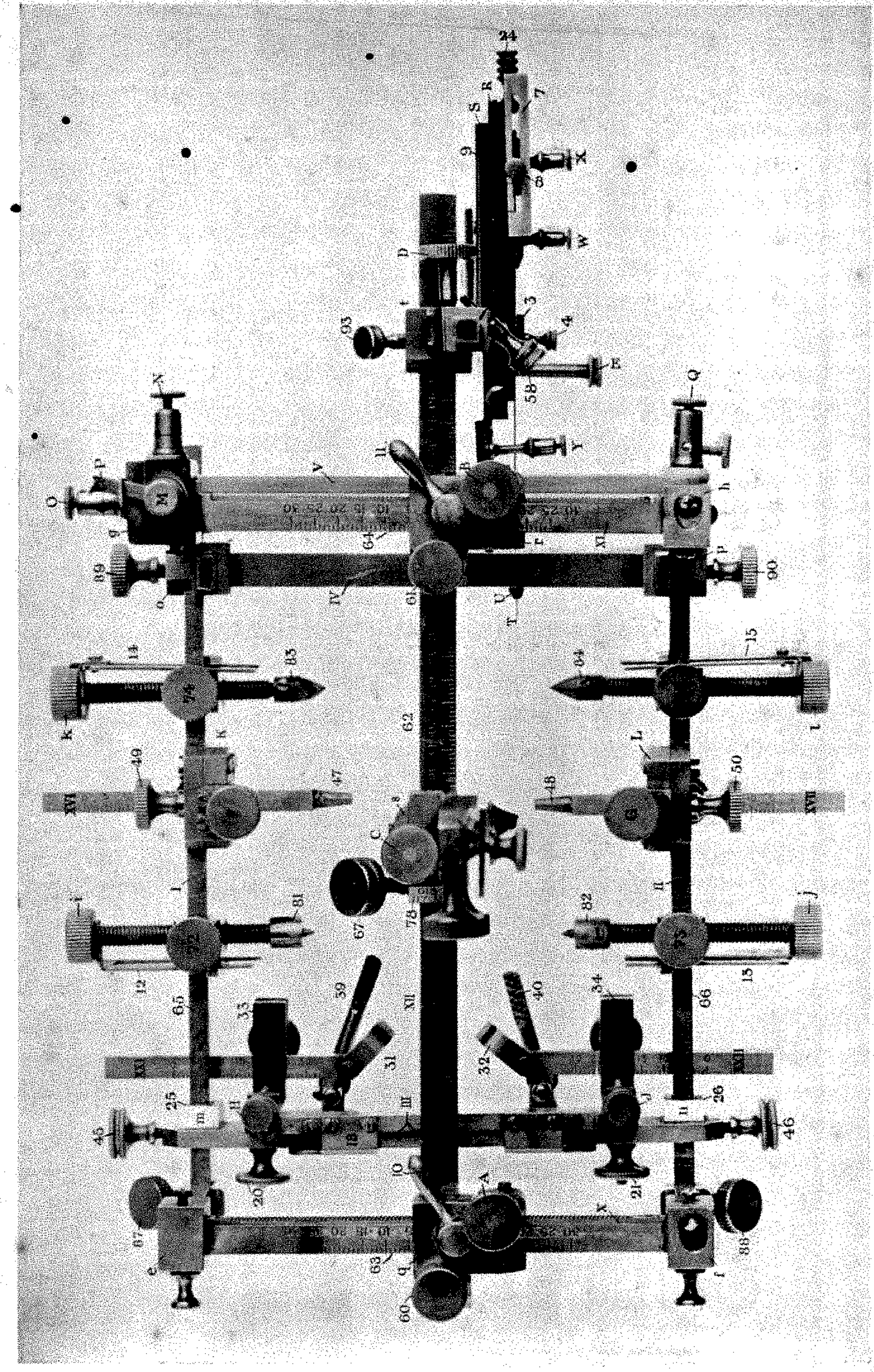

Fig. 6.

I.—*Clarke's stereotaxic apparatus for directing an insulated needle by graduated movement in three planes.*

I.—Plan.

No. I. Plan.—Roman Numerals.

I & II	Right and left lateral bars of horizontal frame.
III	Frontal bar, comprising nasal and orbital plates.
IV	Occipital bar.
V	Occipital stay.
X XI	Anterior and posterior transverse guides.
XII	Sagittal guide.
XVI XVII	Right and left aural pivots, horizontal.
XXI XXII	Right and left infra-orbital bracket bars.

Capital Letters.

A & B	Anterior and posterior pinions for racking sagittal guide on transverse guides.
C	Pinion for racking needle carrier on sagittal guide.
D	Pinion for racking sheath on vertical guide.
E	Pinion for racking bed of needle forward on sheath.
F G	Right and left screws for aural adjustment of horizontal frame.
H J	Right and left screws for orbital adjustment of horizontal frame.
K L	Right and left aural adjustment fitting.
M	Terminal for cathode lead from battery or coil.
N	Terminal for cathode lead to needle.
O	Terminal for cathode lead to live stop.
P	Switch.
Q	Terminal for anode leads, battery and needle.
R	Vulcanite bed of needle holder.
S	Sheath of needle holder.
T	Needle.
U	Stop.
W	First needle terminal.
X	Second needle terminal.
Y	Live stop terminal.

Small Letters.

e f	Right and left terminal joints of anterior transverse guide.
g h	Right and left terminal joints of posterior transverse guide.
i j	Right and left anterior lateral frame clamps.
k l	Right and left posterior lateral frame clamps.
m n	Right and left sliding joints of nasal plate.
o p	Right and left sliding joints of occipital bar.
q r	Two-way travelling joints of anterior and posterior transverse guides.
s	Needle carrier travelling joint.
t	Vertical guide two-way joint rack and slide.

Ordinary Numerals.

3	Vulcanite clamp on needle holder.
4	Screw for vulcanite clamp.
7	Adjustable index on bed of needle.
8	Screw for fixing index on bed of needle.
9	Millimetre scale on sheath graduated 40-0 mm.
10 & 11	Clamps to lock travelling joints on anterior and posterior transverse guides.
12 13	Millimetre scales on right and left anterior lateral frame clamps.
14 15	Millimetre scales on right and left posterior lateral frame clamps.
18 19	Right and left millimetre scales of orbital adjustment.
20 21	Right and left screws for fixing orbital adjustment.
24	Screw to adjust vulcanite bed for second needle.
25 26	Right and left bevelled edge indices on slots of nasal plate.
31 32	Right and left infra-orbital brackets.
33 34	Right and left sliding clamps for infra-orbital bracket bars.
39 40	Right and left horizontal maxillary rods.
45 46	Right and left screws for clamping sliding joints of nasal plate.
47 48	Tapered ends of right and left aural pivots.
49 50	Right and left fixing clamps of aural adjustment.
58	Clamp for fixing rack movement of vertical guide.
60 61	Right and left clamps to fix sagittal guide in longitudinal slots of travelling joints of transverse guides.

Ordinary Numerals (*continued*).

	62	Millimetre scale on sagittal guide.
63	64	Millimetre scales on anterior and posterior transverse guides.
65	66	Millimetre scales on lateral bars of horizontal frame.
	67	Clamp to fix travelling joint of needle carrier (vertical).
72	73	Right and left fixing screws for sliding joints of anterior lateral frame clamps.
	78	Bevelled edge index of travelling joint of needle carrier for scale on sagittal guide.
81	82	Terminal points of right and left anterior lateral frame clamps.
83	84	Terminal points of right and left posterior lateral frame clamps.
87	88	Right and left anterior corner clamps for horizontal frame.
89	90	Right and left clamps for occipital sliding bar.
	93	Clamp for posterior sliding joint on sagittal guide.

frame which coincide with the frontal section plane. When, therefore, the horizontal frame is accurately adjusted, by erecting two perpendiculars of equal length on the centres of the nasal and occipital bars and joining their upper and lower extremities with two straight lines, we can obtain a rectangular quadrilateral figure which represents the sagittal section plane. A similar figure representing the frontal section plane can be constructed from perpendiculars to the lateral bars which fall through the centres of the auditory meatus; in short, by the adjustment of the horizontal frame we secure data for constructing a rectilinear framework or cage corresponding to the three section planes of the head, which can be used for measurement and to direct a needle to any depth perpendicular to any section plane and at any distance from the other two, or, in other words, to any point of known distance from the three inner surfaces of any of the segments into which the head is divided by the three section planes.

These considerations show that the adjustment of the horizontal frame is of primary importance, and the means by which it is effected require some explanation. It has been mentioned that the base line is drawn through the middle of the lower margin of the orbit to the centre of the auditory meatus on each side and that the zero horizontal line is drawn parallel to the base line but at a convenient distance above it, namely, one-fourth of the height of the inter-aural frontal line. The adjustment of the horizontal frame to the zero horizontal plane is effected by two little pieces of mechanism called the aural and orbital adjustments, which enable the operator to bring the lower border of the horizontal frame to the correct height above the base line at these two points without difficulty.

(1) *The Aural Adjustment.*—In the illustration (fig. 7) two upright columns will be seen on the upper surface of the lateral bars. Each of them has a screw (G) at the top which raises and lowers a short vertical rod graduated in millimetres on its outer surface (XIX); this

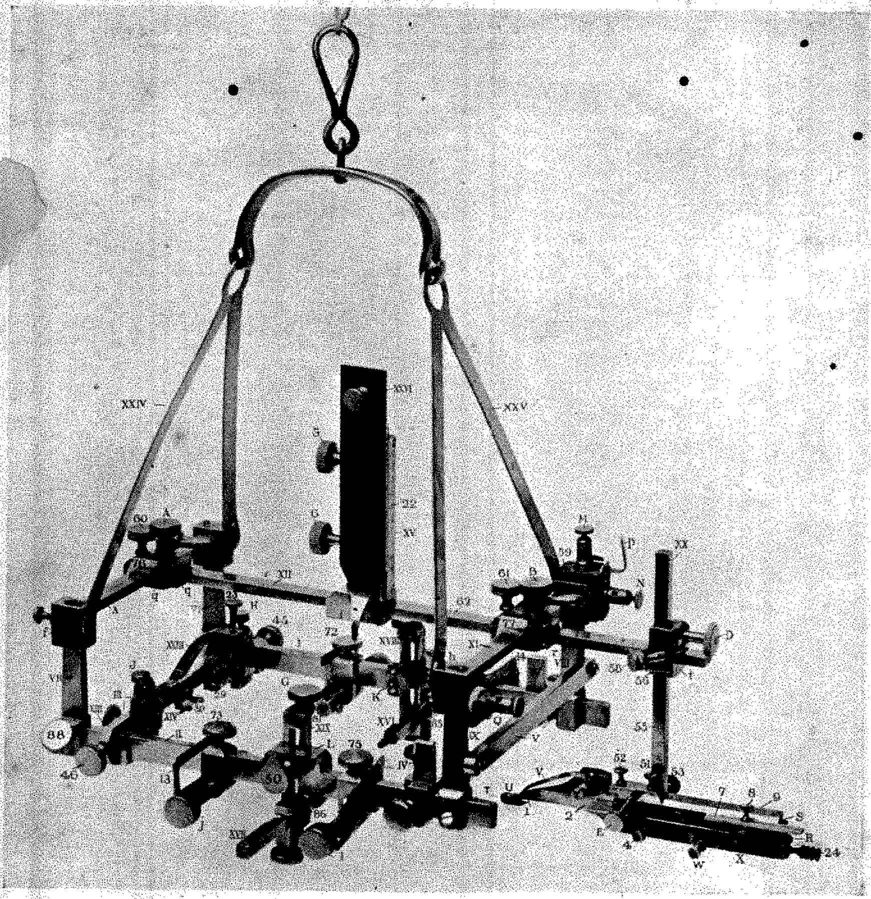

Fig. 7.

Side Elevation of Clarke's instrument.

Roman Numerals.

I II	Right and left lateral bars of horizontal frame.
III	Frontal bar.
IV	Occipital bar.
V	Occipital stay.
VI VII VIII IX	Right and left anterior and right and left posterior corner columns.
X XI	Anterior and posterior transverse guides.
XII	Sagittal guide.
XIII	Nasal plate.
XIV	Orbital plate.
XV	Needle carrier, vertical.
XVI XVII	Right and left aural pivots, horizontal.
XVIII XIX	Right and left aural pivots, vertical.
XX	Vertical guides.
XXIII	Supra-orbital stay.
XXIV XXV	Anterior and posterior slings.
XXVI	Dummy needle.

Capital Letters.

A	B	Pinions for racking sagittal guide on anterior and posterior transverse guides.
	C	Pinion for racking needle carrier on sagittal guide.
	D	Pinion for racking vertical guide.
	E	Pinion for racking needle bed on sheath.
	G	Screw of left aural adjustment of horizontal line.
H	J	Right and left screws of orbital adjustment of horizontal line.
K	L	Right and left aural adjustment fitting.
	M	Terminal for battery lead ; cathode.
	N	Terminal for needle lead ; cathode.
	P	Switch.
	Q	Terminal for battery and needle leads ; anode.
	R	Vulcanite bed of needle holder.
	S	Sheath of needle holder.
	T	Needle.
	U	Stop.
	V	Live stop.
	W	Needle terminal, first.
	X	Do. do. second.
	Y	Terminal for live stop.

Small Letters.

e	f	Right and left terminal joints of anterior transverse guides.
	h	Left terminal joint of post, transverse guide.
	j	Left anterior lateral frame clamp.
	l	Left posterior lateral frame clamp.
q	r	Two-way travelling joints on anterior and posterior transverse guide.
	t	Two-way joint rack and slide on vertical guide.

Ordinary Numerals.

	1	Neck of sheath of needle holder.
	2	Shoulder of sheath of needle holder.
	4	Screw of vulcanite clamp on needle holder.
5	6	Screw for clamping needle holder in vertical carrier.
	7	Adjustable index on bed of needle.
	8	Screw for fixing adjustable index.
	9	Millimetre scale on sheath of needle holder.
	13	Millimetre scale on left anterior lateral frame clamp.
	14	Millimetre scale on left posterior lateral frame clamp.
	22	Millimetre scale on needle carrier.
	23	Screw to depress forehead on supra-orbital brackets.
	24	Screw to adjust sliding bed of second needle.
29	30	Right and left supra-orbital brackets.
45	46	Screws for clamping right and left sliding joints of nasal plate.
	50	Fixing clamp of left aural vertical adjustment.
51	52	Screws for fixing needle pinion.
	53	Screw for attaching needle holder to vertical guide.
	55	Millimetre scale on vertical guide.
	56	Bevelled edge of index millimetre scale of vertical guide.
	58	Clamp for fixing rack motion of vertical guide.
	59	Vulcanite insulator of cathodal terminal.
60	61	Clamps to fix sagittal guide in sliding joints of anterior and posterior transverse guides.
	62	Millimetre scale on sagittal guide.
72	73	Fixing screws for sliding joints of right and left anterior lateral frame clamps.
	75	Fixing screw for sliding joint of left posterior lateral frame clamp.
76	77	Bevelled edge indices for scales on anterior and posterior transverse guides.
	81	Terminal point of right anterior lateral frame clamp.
85	86	Right and left slots for posterior lateral frame clamps for small animals.
	88	Right and left anterior corner clamps for horizontal frame.

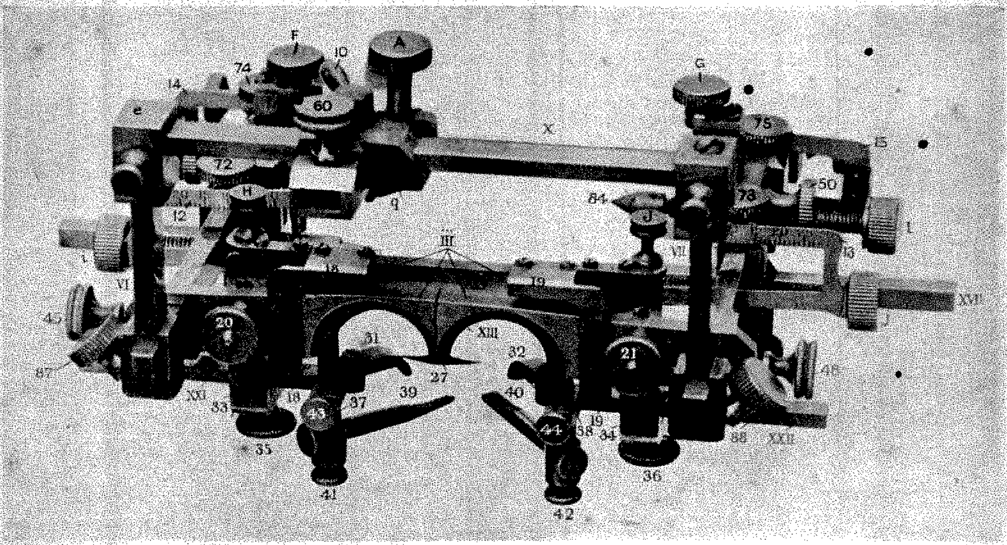

FIG. 8.

Front Elevation (anterior half) with orbital adjustment for various animals.

Roman Numerals.

III	Frontal bar.
VI VII	Right and left anterior corner columns.
X	Anterior transverse guide.
XIII	Nasal plate.
XIV	Orbital plate.
XVII	Left aural pivot, horizontal.
XXI XXII	Right and left infra-orbital bracket bars.

Capital Letters.

A	Pinion for racking sagittal guide on anterior transverse guide.
F G	Screws for right and left aural adjustment of horizontal line.
H J	Screws for right and left orbital adjustment of horizontal line.

Small Letters.

e	Right terminal joint of anterior transverse guide.
i j	Right and left anterior lateral frame clamps.
l	Left posterior lateral frame clamp.
q	Two-way travelling joint of anterior transverse guide.

Ordinary Numerals.

10	Clamp to lock travelling joint on anterior transverse guide.
12 13	Millimetre scales on right and left anterior lateral frame clamps.
14 15	Millimetre scales on right and left posterior lateral frame clamps.
18 19	Right and left millimetre scales of orbital adjustment.
20 21	Right and left screws for fixing orbital adjustment.
27	Needle indicating lower border of nasal plate, and therefore anterior limit of horizontal frame.
31 32	Right and left infra-orbital brackets.

Ordinary Numerals (continued).

33	34	Right and left sliding clamps for infra-orbital bracket bars.
35	36	Screws for clamping right and left sliding clamps for infra-orbital bracket bars.
37	38	Right and left vertical maxillary rods.
39	40	Right and left horizontal maxillary rods.
41	42	Screws for clamping right and left horizontal maxillary rods.
43	44	Screws for clamping right and left vertical maxillary rods.
45	46	Screws for clamping right and left sliding joints of nasal plate.
	50	Fixing clamp of left aural adjustment vertical.
	60	Clamp to fix sagittal guide in travelling joint of anterior transverse guide.
72	73	Right and left screws for fixing sliding joints of anterior lateral frame clamps.
74	75	Right and left screws for fixing sliding joints of posterior lateral frame clamps.
	84	Terminal point of left posterior lateral frame clamp.
87	88	Right and left anterior corner screws of horizontal frame.

is the vertical bar of the aural pivot. Its lower end terminates in a clamp which carries another graduated rod at right angles to it, the horizontal bar of the aural pivot (XVI XVII); this bar slides in the clamp perpendicularly to the sagittal plane and can be fixed by a screw in the clamp. Its inner extremity tapers slightly (fig. 6, 47) and fits accurately into the funnel of the ear plug. These conical plugs have been described on p. 57; they are fitted into the meatus, and the frame lowered over the head of the animal sufficiently to allow the horizontal aural pivots to engage the ear plugs. They are pushed into the funnels to exactly the same distance measured by the millimetre scales on the horizontal bars of the pivots, and when these are the same length they are fixed by the screws. Thus in practice these are the first lateral adjustments made, and by their equality these pivots first approximately centre the head in the sagittal plane. If the height of the horizontal line above the base line is known—suppose it is 10 mm.—the vertical aural pivot bar is set at 10 mm. by its scale and screw, and this brings the lower border of the frame 10 mm. above the centre of the meatus; but generally the height of the vertex above the meatus is not known and has to be measured in the apparatus, and the first adjustment of the vertical height of the aural pivots is only approximate and provisional. The measurement of the frontal line is made by provisionally fixing the aural pivots at 10 mm. and then dropping a dummy needle (fig. 7, XXVI) vertically by the needle carrier (fig. 7, XV) on to the vertex. The scale on the needle carrier gives the distance from the vertex to the horizontal plane, and this, plus the provisional setting of 10 mm., gives the whole height. If this exceeds or is less than 40 mm. then corrections are made accordingly in the aural and orbital adjustments (*see* figs. 5 and 7).

(2) *The orbital adjustment* for the monkey is somewhat different from that which is employed for other animals, and will be described first.

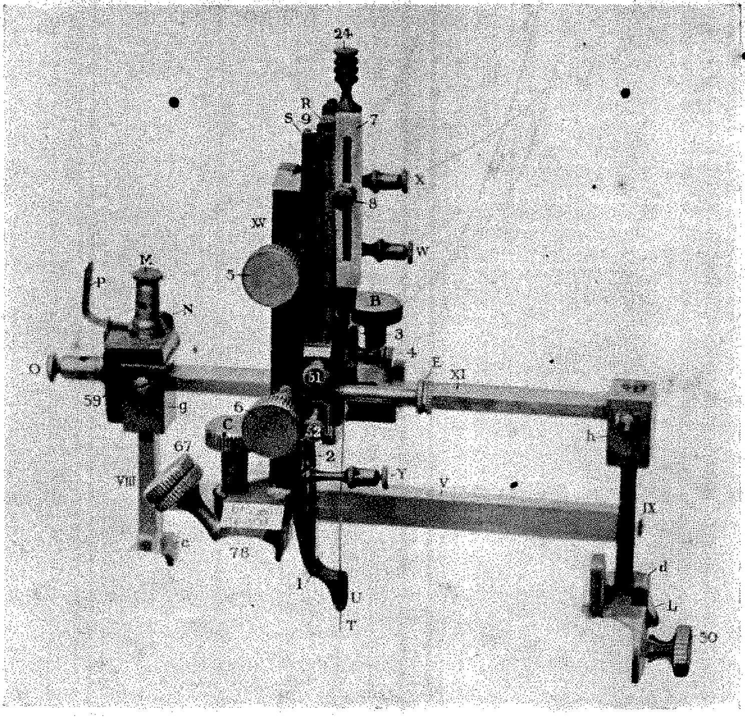

FIG. 9.

Front Elevation (posterior half), with needle mounted for vertical insertion.

Roman Numerals.

V	Occipital stay.
VIII IX	Right and left posterior corner columns.
XI	Posterior transverse guide.
XV	Needle carrier, vertical.

Capital Letters.

B	Pinion for racking sagittal guide on posterior transverse guide.
C	Pinion for racking needle carrier on sagittal guide.
E	Pinion for racking bed of needle holder in sheath.
L	Left aural adjustment fitting.
M	Terminal for battery lead; cathode.
N	Terminal for needle lead; cathode.
O	Terminal for live stop lead; cathode.
P	Switch.
R	Vulcanite bed of needle holder.
S	Sheath of needle holder.
T	Needle.
U	Stop.
W	Terminal of first needle; anode.
X	Terminal of second needle; cathode.
Y	Live stop terminal.

Small Letters.

c d	Right and left posterior corner joints of horizontal frame.
g h	Right and left terminal joints of posterior transverse guide.

Ordinary Numerals.

1	Neck of sheath of needle holder.
2	Shoulder of sheath of needle holder.
3	Vulcanite clamp on bed of needle holder.
4	Screw for clamp on bed of needle holder.
5 6	Screws for clamping needle holder in vertical carrier.
7	Adjustable index on bed of needle.
8	Screw for fixing index on bed of needle.
9	Millimetre scale on sheath of needle holder.
24	Screw to adjust sliding bed for second needle.
50	Fixing clamp for left aural adjustment.
59	Vulcanite insulator of cathodal terminal.
67	Clamp to fix travelling joint of needle carrier.
78	Bevelled edge index on travelling joint of vertical needle carrier for scale on sagittal guide.

The front of the horizontal frame is formed by the frontal bar, which consists of two thin plates, one in front of the other, and held together by two screws (fig. 10, 20 21). They are called nasal (the front one, XIII) and orbital plates (the rear one, XIV) respectively; their connection permits a vertical sliding movement between them, regulated by the screws (fig. 10, H J) and indicated by the millimetre scales (18-19) on the face of the nasal plate. The latter is extended laterally and slotted near its extremities, which thus form sliding joints on the lateral bars (fig. 10, m n). As the upper surfaces of these latter are graduated in millimetres backwards and forwards from a point opposite the centre of the auditory meatus, which is marked zero (and the posterior edges of the slots are bevelled as indices), the distance of the posterior surface of the orbital plate from the inter-aural frontal line is read off at once. The orbital plate is brought into contact with the forehead by sliding the whole adjustment backwards on the lateral bars, to which the nasal plate is fixed by the clamping screws as described (fig. 10, 45 46). The lower border of the nasal plate, of course, has, with the rest of the horizontal frame, to coincide with the horizontal section plane. This is effected as follows: Where the orbital plate is in contact with the forehead there are attached to it on each side small horizontal slightly convex plates, the superior orbital brackets (fig. 10, 29-30), which project backwards about 6 mm. beneath the supra-orbital arches. An arm (XXIII), the "supra-orbital stay," which extends back about 2 cm. over the forehead and carries a vertical screw (fig. 10, 23), affords a simple means by which the supra-orbital arches are kept in contact with the orbital brackets on which they rest. The brackets and stay, therefore, like the blades of a pair of forceps, hold the frontal bone to the orbital plate, and the vertical movement and millimetre scales between this and the nasal plate enable the operator to see and regulate the height of the supra-orbital arch above the lower edge of the horizontal frame, *i.e.*, of the nasal plate. As the vertical diameter of the orbit is taken beforehand with callipers (in the average Rhesus, as already stated, it is 20 mm.), if the distance of the edge of the frame below the supra-orbital arch is known its distance above the lower margin of the orbit is known also. The lower border of

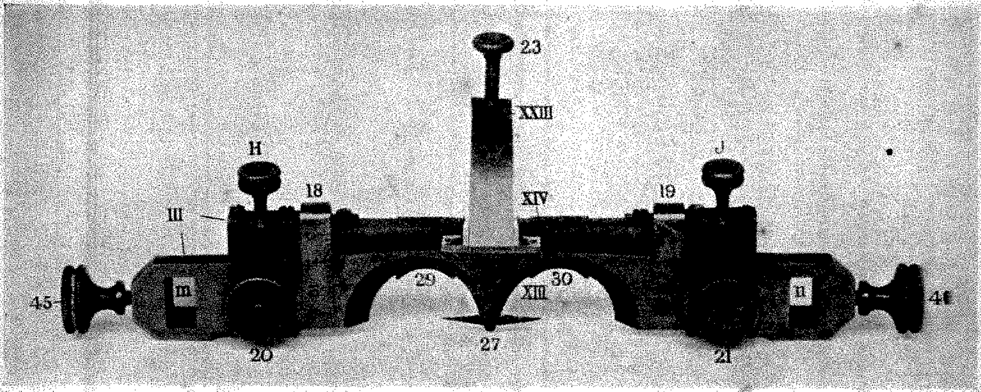

FIG. 10.

Orbital Adjustment for Monkey.—Front Elevation.

Roman Numerals.

III	Frontal bar.
XIII	Nasal plate.
XIV	Orbital plate.

Capital Letters.

H J	Right and left screws for orbital adjustment of horizontal frame.

Small Letters.

m n	Right and left sliding joints of nasal plate.

Ordinary Numerals.

18	19	Right and left millimetre scales of orbital adjustment of horizontal frame.
20	21	Right and left screws for fixing nasal and orbital plates.
	23	Screw to depress forehead.
	27	Needle indicating lower border of nasal plate, and therefore horizontal frame.
29	30	Right and left supra-orbital brackets.
45	46	Screws for clamping right and left sliding joints of nasal plate.

the horizontal frame is therefore made to coincide with the horizontal section plane at the specified height (one-fourth of the frontal line) above the lower margin of the orbit by the screws (fig. 10, H J) and then fixed by the screws (20 21). The orbital adjustment being thus completed, the bevelled edges (fig. 6, 25 26) behind the nasal bar slots will now on the average read 47 mm. on the pre-aural scales of the lateral bars on both sides, and the nasal plate is fixed by the screws (fig. 10, 45 46). The occipital bar (fig. 6, IV) is next brought forwards into contact with the occiput, the bevelled edges of its sliding joints (fig. 6, o p) reading on the average 33 mm. on the post-aural scale of the horizontal frame bar, and it is also clamped.

The scale of the aural (fig. 7, XVIII XIX) adjustments is set at 10 mm. (if this be one-fourth of the frontal line), and then the four lateral frame clamp points (fig. 6, 81 82, 83 84) are screwed in sufficiently to secure the head firmly in its position. Each clamp is provided with a millimetre scale to ensure that the corresponding pairs, pre-aural and post-aural, are screwed into the same distance on each side. Since the same precaution was observed in adjusting the aural pivots the sagittal centreing of the head is adequately provided for by these six lateral supports thus accurately measured to corresponding lengths. After the clamping points have been fixed the occipital bar can be removed to give free access to the cerebellum. The horizontal frame has thus been accurately adjusted so that its lower border coincides with the zero horizontal line, and it now constitutes the foundation of a frame which corresponds with the three section planes and provides for directing a needle by them. Before describing the needle mechanism a few words are required on the adjustments for various other animals besides monkeys and on corrections for size, for hitherto we have only considered the average rhesus. As the measurement of the head in the apparatus, in correcting for size, &c., involves the use of some parts which have not been described it will be best to complete the description of the instrument and then consider the remaining questions of measurement.

Adjustment for animals below primates.—The instrument can be applied to any moderately sized mammals and to the larger birds, such as geese and ducks. We have not attempted to enlarge it so as to include dogs because in almost every respect the cat's brain is superior to the dog's for elementary neurological purposes; the nerve tracts are better marked, the size of the encephalon is more convenient for serial sections, and, most important of all, cats' heads are of much more uniform size and shape than those of dogs; in fact, the endless variations in the size and shape of dogs' heads make them unsuitable for a research involving accurate cranio-encephalic topography. The orbital adjustment is the only one that needs modification to suit the heads of animals below the primates, for in all cases the range of movement in other parts of the apparatus is sufficient for any variation of size that is required, the aural

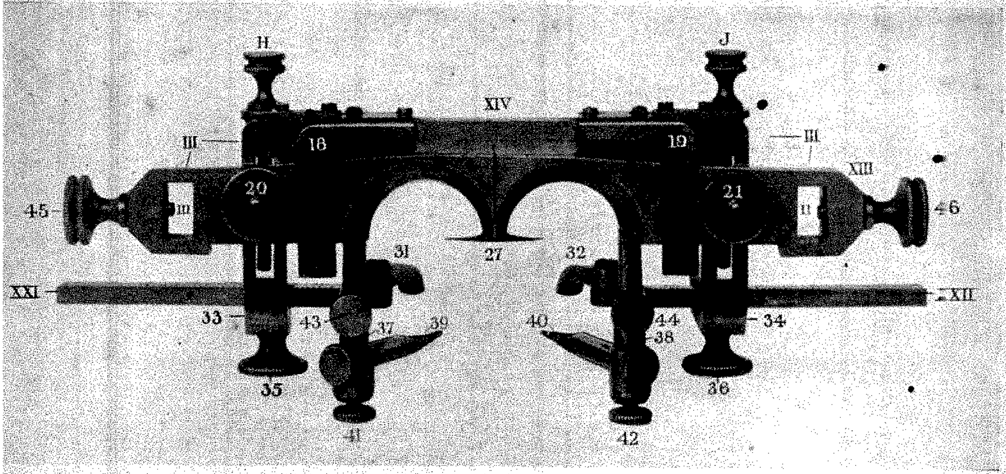

Fig. 11.

Orbital Adjustment for various Animals.—Front Elevation.

Roman Numerals.

III	Frontal bar.
XIII	Nasal plate.
XIV	Orbital plate.

Capital Letters.

H	J	Right and left screws for orbital adjustment of horizontal frame.

Small Letters.

m	n	Right and left sliding joints of nasal plate.

Ordinary Numerals.

18	19	Right and left millimetre scales of orbital adjustment of horizontal frame.
20	21	Right and left screws for fixing nasal and orbital plates.
	27	Needle indicating lower border of nasal plate, and therefore horizontal frame.
31	32	Right and left infra-orbital brackets.
33	34	Right and left sliding joints for infra-orbital bracket bars.
35	36	Right and left screws for fixing sliding joints (33 34).
37	38	Right and left maxillary rods, vertical.
39	40	Right and left maxillary rods, horizontal.
41	42	Right and left screws for clamping horizontal maxillary rods.
45	46	Right and left screws for clamping sliding joints of nasal plate.

adjustment fitting the form of ear plug which may be required for any species of animal.[1]

Though the modification of the orbital adjustment we suggest as more useful[2] for animals below the monkey looks different (*see* fig. 11), anyone who has followed the description of the adjustment for the monkey will find the principle the same and the modifications easy to understand. The head, and therefore the lower border of the orbit, is raised and lowered in relation to the lower border of the frame (*i.e.*, of the nasal plate, fig. 11, XIII) by a vertical sliding motion between the nasal and orbital plates regulated by screws (fig. 11, H J) and indicated by millimetre scales (fig. 11, 18 19) on the face of the nasal plate—all this is the same in plan as before. The only difference is that while the orbital plate is connected to the forehead of the monkey by the superior orbital brackets and stay, which grasp the frontal bone like the blades of a pair of forceps, in this pattern the orbital plate is attached to the superior maxilla by inferior orbital brackets (fig. 11, 31 32) and horizontal maxillary bars (39-40). The former project a few millimetres into the orbit over its lower edge, the latter similarly into the mouth, and both together hold the superior maxilla, grasping it like a pair of forceps by the lower edge of the orbit and the upper teeth. In birds the horizontal maxillary bars pass under both mandibles instead of between them. The maxillary bars consist of vertical (fig. 11, 37 38) and horizontal (39 40) portions freely adjustable in all directions; they and the orbital brackets are supported on graduated arms (fig. 11, XXI XXII), supported and sliding in clamps (fig. 11, 33 34) which allow them a transverse motion; the clamps are fixed to the orbital plate, and thus, being attached to the nasal plate, have a longitudinal motion on the lateral bars. Both infra-orbital brackets and maxillary bars have therefore a transverse and longitudinal movement by which they can be adjusted to heads of any size.

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[1] It should be mentioned that in the cat the orifice of the meatus is so covered by the pinna that division of the latter is necessary to admit the ear plugs; the incision should be made in the line of the postero-inferior edge of the tragal portion of the pinna.

[2] Possibly for any species.

Mechanism for Directing the Excitation or Electrolytic Needle.

We have pointed out the data for the mechanical direction of a needle in any plane by the adjustment of the horizontal frame, and the illustrations (fig. 6 and 7) show how one method of giving effect to the principles of localization we have described are carried out in the instrument. Four rigid perpendiculars, the corner columns (fig. 7, VI VII VIII IX), are fixed to the corners of the horizontal frame and joined in pairs by two transverse graduated bars, the anterior and posterior transverse guides (figs. 6 and 7, X XI); the centre of each bar corresponding to the median sagittal plane is marked zero and graduated in millimetres from that point on each side. Each transverse guide carries a travelling two-way joint (figs. 6 and 7) with rack and pinion motion.

These joints travel on the transverse guides and at the same time support and carry with them a long graduated bar, the sagittal guide (figs. 6 and 7, XII). This bar is fixed in the slots of the two-way joints in such a position that the zero marked on it corresponds to the inter-aural frontal line, and the sagittal guide is graduated forwards and backwards from this point. The only movement of the sagittal guide is a lateral one, by means of the travelling joints on the transverse guides; longitudinally it is a fixed base on which the arm carrying the horizontal needle slides by a simple joint and on which also the vertical (*see* fig. 7, XV) needle carrier connected perpendicularly to it by a travelling joint moves forwards and backwards from the zero inter-aural frontal plane. The excursions of the needle carriers are indicated by the millimetre scale on the sagittal guide.

The Needle Holder and its Movements.

(1) The needle, which may be single or double, consists of an iridio-platinum wire insulated nearly to the point in a capillary glass tube, and is clamped on a vulcanite plate, the bed. The glass is held by a vulcanite clamp, from which it is separated by a small piece of soft rubber. The proximal end of the projecting wire is fixed in a metal clamp secured by the terminal, which is screwed firmly down upon it, and electrically connects the needle with the lead from the coil or battery as the case may be The bed slides by a bevelled edge on each side on a sheath, which tapers in front into a shoulder and neck, and the latter terminates in a small flattened vulcanite cylinder, the stop, perforated to permit the passage of the needle, which can be advanced and withdrawn through the stop by a rack and pinion movement of the bed on the sheath, registered by an adjustable index on the bed, and a graduated millimetre scale on the sheath. This gives the needle an excursion of 40 mm. The perforation in the stop is formed by a lateral slit open on one side to admit the needle and then closed by a fine brass rod which projects a little beyond the stop, and at its proximal end is attached to the shoulder of the sheath by a terminal which receives a lead if required and makes contact with the rod; this rod then constitutes what we call a "live stop," and may be used for so-called unipolar excitation. It also serves the purpose of exercising slight pressure on the needle in its groove steadying it, and serves as an electrode when required. It is convenient when a single wire is employed. As we show later, in deep punctures faradization of the brain by a long arc stimulation is highly objectionable

since if one electrode is formed by a needle point and the other by some form of surface contact the current traverses many excitable areas and may produce confused and misleading results, but in making electrolytic lesions the single needle is almost indispensable, and as we never electrolyze without at least one faradic excitation, and generally several, the difficulty is to get a satisfactory stimulation when the single needle is used. It was to meet this that the "live stop" was devised, and in practice we find that as it makes a small surface contact close to the needle, the current is notably confined to its track, thus very much diminishing the escape of current and irregular effects of wider and more distant surface contacts. The disadvantage electrolytically is the exaggeration of the needle track.

The essential parts of the needle holder are thus the bed and the sheath, the latter including the neck and stop. As the needle is carried forwards through the stop the adjustable index attached to the bed indicates the excursion of the needle on a scale on the sheath, which is so graduated that as the needle is advanced the index approaches zero. The object of this is that as the needle penetrates the brain perpendicular to either the horizontal or frontal zero section planes, it is convenient that the index should arrive at zero when the point of the needle reaches the zero plane.

The instrument is constructed to direct the needle at will into any part of the brain from two positions: (1) Vertical from above, and (2) horizontal from behind.

(1) In the vertical position the sheath of the needle bed slides in a slot in the carrier, where it can be fixed with two screws. It is perpendicular to the sagittal guide, and, of course, to the horizontal section plane. It has been explained that the carrier travels longitudinally on the sagittal guide from a zero, which corresponds with the inter-aural frontal section plane, and laterally on the transverse guides to right and left of the median sagittal plane. By these two movements the needle can be brought over any square millimetre in the horizontal plane. For the vertical movement the connection between the sheath and the carrier is used as a coarse adjustment. For this purpose there is a scale on the carrier and an index on the sheath (figs. 9 and 7). The scale is originally graduated as follows: The sheath is pushed downwards till the distal surface of the stop is level with the lower border of the horizontal frame. This point is marked zero on the scale, and the graduation is made as the sheath is drawn up. This scale therefore always indicates in millimetres the distance of the stop above the

zero horizontal line. In use the sheath is pushed down till the stop is at a convenient point, commonly the surface of the brain, and it is fixed there; the scale on the carrier (XV) then shows how many millimetres separate the stop from the horizontal line. The needle is then advanced till its point is exactly flush with the surface of the stop, and the adjustable index on the bed is set at the same figure on the scale on the sheath. If the stop, according to the scale on the carrier, is 30 mm. above the horizontal line, and the ivory index is set at 30, then as the needle penetrates the brain the figure on the sheath scale will always show the distance of the point from the horizontal section plane, and when it arrives there the index will be at zero.

(2) In the second or horizontal position the needle holder is connected to the sagittal guide in a different way. In the illustration it is shown connected to the hinder end of the sagittal guide as follows: The sheath carrying the bed and needle is fixed at right angles to the lower end of a vertical guide (fig. 7, XX) by two screws (fig. 7, 53). The vertical guide is connected with the sagittal guide by a two-way joint, one slot of which (horizontal) slides over the sagittal guide and can be fixed at any point by a screw (fig. 6, 93). The other slot of the joint is vertical and the vertical guide is worked up and down in it by a rack and pinion (fig. 7, D). The vertical guide is graduated in such a way that when the point marked zero is opposite the bevelled edge of the joint (fig. 7, 56) which serves as the index, the needle is on the horizontal line, and the graduations above and below zero show the vertical distance of the needle above or below the horizontal line.

The transverse movements of the sagittal guide to right and left of the median sagittal plane convey the same motion to the needle, and the vertical and sagittal guides in this way afford the two movements required to bring the needle opposite any square millimetre on the frontal plane. The third movement, that of the needle towards the frontal plane, is a double one as in the first position, but differently arranged. The coarse adjustment is the movement of the whole needle holder and stop towards the frontal section plane. This is effected by the sliding joint (fig. 6, t) on the sagittal guide. The bevelled edge of the joint is an index for the graduated scale on the guide and indicates the distance of this edge from the interaural plane, *i.e.*, zero on the sagittal guide. The distal surface of the stop (U) is 50 mm. in front of the bevelled edge. As the distance of the bevelled edge from the frontal line is known, that of the stop from this line is known also. For example, if the bevelled edge is at 80, the anterior surface of the stop is 30 mm. behind the frontal section plane. The point of the needle is racked flush with the surface of the stop and the adjustable index (fig. 6, 7) set at 30. As the needle advances towards the frontal line the index travels towards zero on the scale on the sheath (fig. 6, 9), and when it reaches zero the point of the needle arrives at the zero frontal inter-aural plane.

Needles.—These are made of iridio-platinum (20 per cent. iridium), about 10 cm. long, pointed and of various calibres, according to the size of the electrolytic lesion required, which depends on various considerations. For stimulation fine needles are required (30 to 32 on the English standard wire gauge), about 0·22 mm. in diameter; they are fitted into the smallest glass tubes which will take them, about 25 to 26 gauge. We have not found it desirable to use finer needles than this as a rule. In every excitation experiment there are some points which must be marked by a small electrolysis, sometimes to record a noteworthy response, and in any case to serve as indicators to verify or correct the position of the part investigated after the brain has been fixed and sectioned. Owing to the high resistance, however, there is a limit to the calibre of needles which can be employed with advantage for electrolysis. Illustrations of the needles which we are at present using, and showing both the actual size and enlargement, are given in fig. 12. They represent three varieties: the single, the double-barrelled, and the concentric. In all cases the insulation is by a capillary glass tube. The following are measurements of needles in use at present showing the relations of needles and glass tubes. The measurements are given in millimetres and in the English standard wire gauge:—

	Wire gauge	mm.		Wire gauge	mm.
1 Single needle, fine ...	32 ...	0·19	... Glass tube ...	27 ...	0·34
2 Single needle, large ...	25 ...	0·45	... Glass tube ...	21 ...	0·70
3 Double barrel ...	30 ...	0·27	... Glass tube ...	24 ...	0·50
	30 ...	0·27	... Glass tube ...	24 ...	0·50

The single needle is the most convenient when only an electrolytic lesion is required; it gives a better point, is most easily introduced, with the least effect on the tissues, its track being scarcely recognizable in sections; its size and the amount of platinum exposed are very easily regulated and consequently the size of the lesion; the latter, when the needle is an anode, is generally spherical, circumscribed and precisely defined. For preliminary stimulation to verify the position, &c., of the needle, it is best to employ it with the live stop, but this must not, of course, be used for any subsequent electrolysis or it will produce a kathodal lesion on the cortex. When stimulation is the principal object a single needle is undesirable, since even the live stop gives too large an area of excitation, and a short arc stimulus is far more satisfactory. Either the double-barrelled or concentric needle shown in fig. 12 may be used for short arc stimulation. The double-barrelled needle penetrates well, makes a small wound and has good rigidity. It was a long time before we succeeded in getting two capillary glass tubes fused together, and we have to thank Professor Jackson, of King's College, for the suggestion which made it practicable. This was to fuse two ordinary glass tubes together for a short distance, and then

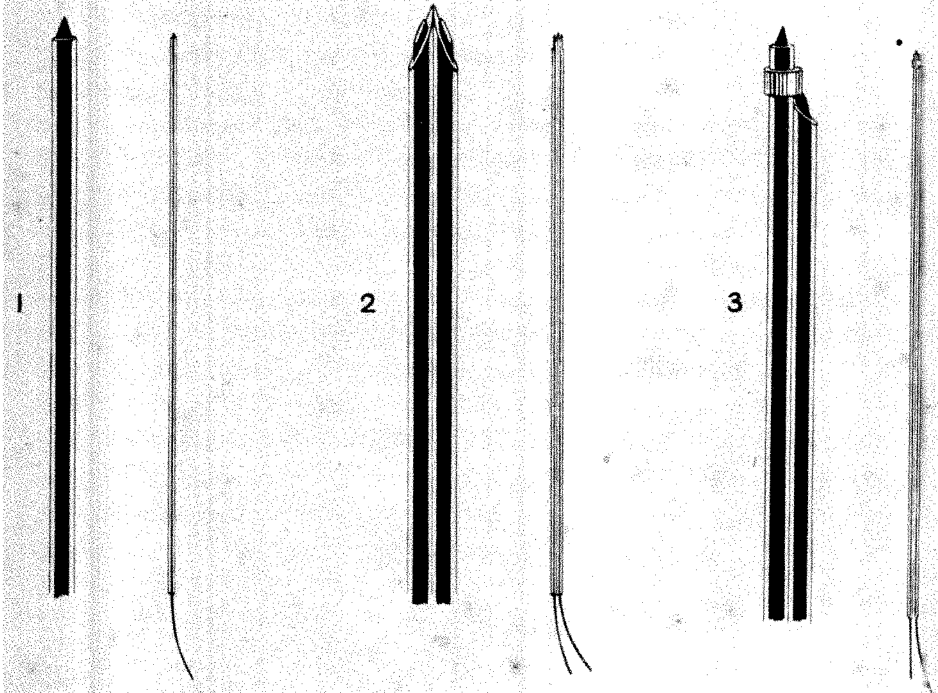

Fig. 12.

Iridio-platinum needles insulated in glass tubes.

1 Single needle. 2 Double-barrelled needle. 3 Concentric needle.
(Actual size and enlarged.)

heat them and draw them out together. This gives excellent results; the tubes are fused together like the barrels of a gun and can be drawn out quite straight and as long and fine as can be wished. They are ground to a point and wires inserted, which are cut parallel to the slanting orifice which terminates in the point. The ends of the wires are thus separated completely from one another by a glass point, round the edge of which the current must pass.

The concentric needle gives the most constant effects, especially where groups of cells in a nucleus are stimulated. It is rather difficult to make, and, unless very well finished, is rather clumsy, less easy to introduce, and makes a larger track than the others. Mr. Rittershaus,[1] who makes them for us, has much improved them, and is now making them with the double-barrelled glass sheath which diminishes these drawbacks. As will be seen from the illustration, they consist of two fine single insulated needles. The wire of one projects about 0·75 mm. beyond the glass, while of the other the wire is drawn out of its glass tube sufficiently to make a little collar round the glass of the first about 0·75 mm. behind the edge of the glass. The end of the needle, therefore, consists of wire, glass, and collar, each 0·75 mm., or about 2 mm. in all, and the current flows backwards and forwards from the point all round to the collar, giving an equally diffused stimulus for a small area round the point of the needle. When an electrolysis is required the point or the collar can be used alone, the point making a very minute, the collar a moderate-sized, and both together a large lesion.[2]

Corrections for Size and Symmetry.

In describing the adjustment of the instrument to the head of the rhesus it was assumed that the animal was a typical example of average measurements. In practice there are nearly always some variations, and they may be considerable; every head, therefore, must be carefully measured and corrections made for irregularities. The procedure we have adopted is as follows: We first take the maximal longitudinal and transverse diameters of the cranium, *i.e.*, above the level of the zygomatic arch as well as the greatest vertical diameter of the orbit, with callipers before applying the instrument; an outline drawing of the head is made to scale on millimetre paper, and all the measurements filled in as they

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[1] Of Huntley Street, Tottenham Court Road.
[2] Mainly kathodal.

are taken (*see* specimen of such outline, fig. 5). The callipers are necessarily not as accurate as the apparatus, and the preliminary measurements with them are checked by reading on the instrument after the head is fixed. The measurements, including the true height (fig. 5, I and II) of the horizontal line shown in the outline sketch, are all filled in, and a chart frozen section which shows the required lamella is selected, and the dimensions of each segment in the experimental animal and the chart section compared. If the error of difference is less than 10 per cent. we usually treat it as negligible, but if it amounts to 1 in 10 or more we make the necessary correction according to a table of equivalents With such corrections and careful adjustment of the apparatus the results are generally accurate in the rhesus. If there is a great difference between the absolute dimensions of the animal's head and the chart section, there is, of course, more likelihood of error, but discrepancies can be in a great measure avoided; thus if there is only one series of frozen sections to work by, animals must be selected which approach it in size, and, of course, if two or three series of sections of different sized animals are available the operator is less restricted. On the question of symmetry the measurements depend on the assumption that the positions of the bony landmarks, *i.e.*, the meatus and orbits, are generally symmetrical. Moderate variations of proportional measurement can be corrected, and though, of course, the fewer such necessary amendments are the better, they are not necessarily inconsistent with accuracy provided they balance, but an irregularity which prevents the inter-aural plane being perpendicular to the sagittal plane is a grave fault We do not find that such serious forms of asymmetry occur in monkeys Of other animals we cannot speak from much experience, but cats' skulls are less regular than monkeys, and more care will be necessary in their selection.

Asepsis.

It is hardly necessary to say that in degeneration experiments every care to maintain asepsis must be observed. It need not be alluded to further here except in relation to the instrument; this is too delicate to bear repeated boiling, and as some portions of it are of vulcanite efficient sterilization by heat is precluded. We keep the whole instrument in absolute alcohol, which does not injure it and has proved satisfactory The glass and platinum needles are easily sterilized in strong acids. The small wounds and the protection from contact afforded by the instrument are very favourable to asepsis and infection ought not to occur.

Preparation of Tissues.

As Marchi's method is so well known and described in text-books we need not do more than mention a few points. We inject the brain of the animal just killed, from the aorta preferably, with Müller's fluid (or Müller and formalin) and preserve in Müller alone, since we think any continued use of formalin interferes with osmic acid staining. It is very desirable when employing this method to cut the brain parallel to the section planes which have been defined in the use of the apparatus (*vid. inf.*), and such section blocks should never be more than 2 mm. thick, cut as soon as the brain is fixed.

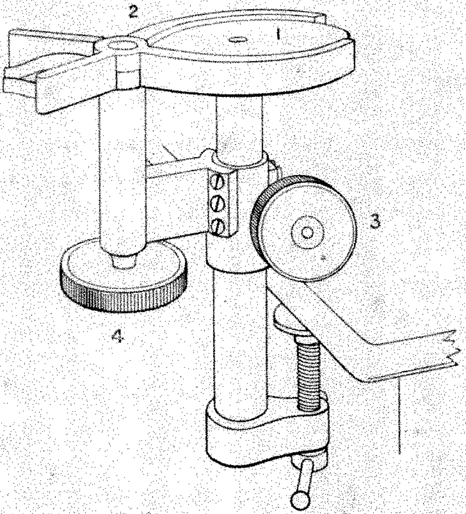

FIG. 13.

Macrotome for cutting brain in slices of known thickness.

1 Plate, raised or lowered by pinion 3.
2 Jaws.
3 Rack and pinion movement to raise and lower plate 1.
4 Clamp to fix jaws 2.

Macrotome.

An illustration is given in fig. 13 of a section instrument, or macrotome, which is useful for this purpose. The brain is divided in one of the section planes. The cut surface is then applied to the plate (1), and the jaws (2) adjusted 2 mm. above the plate. While the brain is well moistened with water, successive slices are cut with a brain knife, keeping the edge of it on the jaws with a short sawing movement. In the sagittal plane the median section can be judged by the eye, but for the other two planes it is necessary to mark the brain; at present the only way of doing this accurately is to adjust the head in the stereotaxic instrument and mark it before it is removed. Thus when it is in the instrument four to six points can be marked by the dummy needle on both sides of the head in either frontal or horizontal planes (preferably in the inter-aural plane); the skull is removed or drilled at these points and the brain marked with a red-hot needle. After the brain, removed from the skull, has been suspended by Retzius's method in Müller's fluid for twenty-four hours, the desired section can be carried through these marks.

We will now proceed to discuss the electrolytic lesion as produced by the instrument just described, and next the procedure of stimulation, since the use of these methods led us to consider and experimentally investigate a number of points of procedure which bear directly on the question of the accuracy to be obtained in all investigations of this kind.

Although a natural order of these two subjects would be (1) stimulation, (2) electrolysis, for that is our experimental procedure, it will be more convenient historically to deal first with the application of electrolysis to the production of localized lesions in the encephalon.

IV.—THE ELECTROLYTIC LESION.

Historical References.

Attention was early directed to the electrolytic method; thus Mr. William Brande, Sir Everard Home, and Sir H. Davy in the *Philosophical Transactions of the Royal Society* for 1809, give an account of some experiments on the electrolysis of animal fluids undertaken by Mr. Brande for Sir Everard Home. In some of these experiments Mr. Brande was assisted by Sir H. Davy.

Various albuminous fluids were employed, including blood and serum, the former of these being in one experiment contained in the vessels of a freshly killed deer.

The general results may be summarized by saying that with strong currents there was always rapid coagulation at the kathode, none with weak currents. With both currents there was slight coagulation at the anode. Davy's explanation of this was that the albumen was kept in solution by alkali, and when this was liberated coagulation of the albumen followed. Brande showed that while strong currents are required to liberate the alkali sufficiently to coagulate the albumen, there is more tendency for slight coagulation to occur at the acid pole with weak currents. With fresh human blood kept at 100° F. and a current from twenty 4 in. double plates employed for fifteen minutes, there was no coagulation nor any change, but a slight difference of colour and the production of acid and alkali at the electrodes.

In experimenting on deer's blood in a blood-vessel, and with serum, strong currents caused a rapid coagulation at the kathode, but a slow and slight deposit of albumen at the anode. Employing a weak current for fifteen minutes, a filament about ¼ in. long was seen adhering to the positive wire, but nothing at the kathode.

Thus the existence of polar differences in the establishment of a coagulation necrosis have long been known. The direct use of electrolysis as a method of causing localized lesions in the central nervous system seems to have been first described by J. Sellier and H. Verger (1898), who produced electrolytic lesions of the thalamus in five dogs with two insulated needles. A current of 9 ma. to 12 ma. being employed for from seven to ten minutes, the lesions obtained were about the size of a pea or grain of maize.

Gustave Roussy [17] also produced a lesion of the thalamus in two cats, two dogs and one monkey. Following the method of Sellier and Verger, he gives a more precise description of the procedure he employed as follows:—

Current.—A battery of 20 elements with galvanometer in circuit using 8, 10, 12 ma., for eight or ten minutes.

Needles.—Iridio-platinum sheathed in glass. Wire not exceeding 8 cm. long, 0·3 mm. calibre and 1 mm. exposed. They were mounted on a vulcanite plate to carry terminals, one in a slot so that the needles could be separated or approached.

The resistance was observed to fall during the passage of the current (*vide* p. 97 in present paper for reference to this point). The circuit was opened and closed by degrees to avoid movements of the animal.

Roussy reached the thalamus in the cat and dog by taking the middle point of the median sagittal line, *i.e.*, a line extending from the superciliary ridge to the occipital protuberance and trephining ½ cm. to 1 cm. behind this point.

Owing, however, to unavoidable want of precision in this method of localization, Roussy found that of twenty experiments, but five, *i.e.*, one-fourth, were available for the research.

Roussy states that Golsinger, of St. Petersburg, in 1895, was the first to employ this method for destruction of the deep tissues of the brain. He used or advocated unipolar electrolysis, one pole being connected with an insulated needle in the brain, the other attached to an indifferent plate electrode on the abdomen. The current he employed varied from 20 to 40 ma., and, according to his measurements, 8 coulombs gave a lesion the size of a pin's head, 36 coulombs a lesion the size of a cherry. Golsinger showed at the Conférence des Médecins de la Clinique des Maladies Nerveux et mentals (St. Petersburg, 1895), the brains of six dogs with isolated lesions produced by this method. Unfortunately we have not been able to see the report of this communication.

Production of the Electrolytic Lesion.

Having determined on electrolysis as the control to electrical excitation we began by investigating the effects of the various forms of electrical currents on the central nervous (cerebral) tissue, and we arrange the results obtained as follows :—

(A) The Lesion as Produced by Sparks from High Tension Currents.

We first endeavoured to obtain lesions by the use of sparks from high tension currents with an interruption of about 100 per second. The electrolytic action of such sparks on water (steam) has been investigated since Perrot's original observations and has received thorough reinvestigation by Professor J. J. Thomson [23] and others. Lesions of the brain so produced we have found to consist of combined electro-thermic, electro-chemical and mechanical effects.

When two needles, 4 mm. apart, were introduced into the cerebral substance to a depth of 5 mm. and the coil started, the result was to cause a rapid swelling and illumination of the superjacent cortex by reason of the passage of sparks causing practically a subcortical deflagration. Macroscopically and microscopically the resultant lesion proved to be a combined laceration and cauterization with no determinate border. The site of one needle pole was crateriform and empty, that of the other was more tubular and filled with gas bubbles, which were present in a diminishing degree along the narrow line of destruction which marked the shortest paths between the needle points.

The restriction of the effects of such a lesion was proved as in the case shown in fig. 14, for, on faradic excitation, the excito-motor cortex immediately in front of the destroyed area was found to be physiologically active close up to the margin of the lesion.

Although the combined effect was thus fairly localized it appeared to us that the degree of destruction by sparks is not sufficiently controllable to be useful for our purpose and we gave it up on this ground.

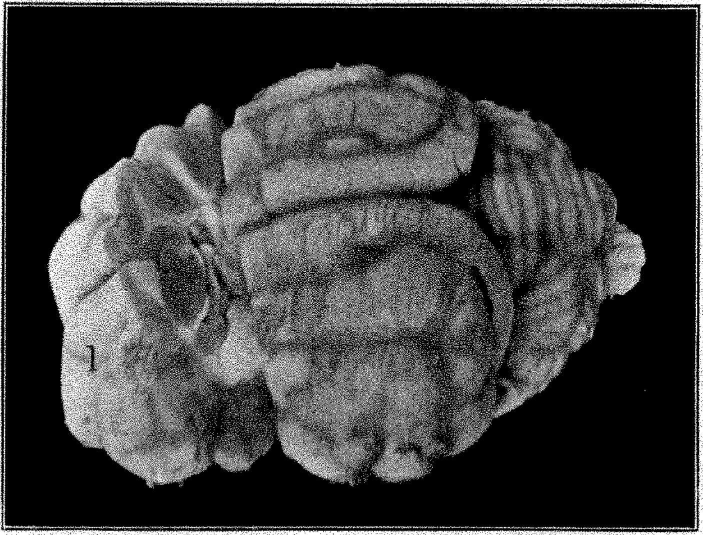

FIG. 14.

Lesion of cerebral cortex made by use of high tension sparks.

1 Spot on normal cortex just in front of the lesion and where excitation proved that the cortex in question was functionally active. (Cat.)

(B) The Lesion as Produced by Constant Currents.

Electrolysis by a constant current is, of course, a familiar subject, but little has been written on the immediate question, namely, the destruction of brain or central nerve tissue by its means, and when we were endeavouring to estimate its qualitative and quantitative effects we found that practically no description of the products obtained from cerebral tissue by the action of each pole existed. We have had therefore to spend a very considerable time in clearing up several points, not only chemical but also mechanical, which attracted our attention early in the research as well as attempting, with the kind assistance of Dr. Gordon

Lane, to form an opinion as to the basis of the chemical changes. We may therefore group the effects under the headings of: (1) *Mechanical;* (2) *Chemical.*

(1) *Mechanical effects.*—(*a*) *Transference.*—The knowledge of the migration of ions prepares one for the acceptance of the fact that in a compound tissue like that of the brain the lesions show a separation and localization of the chemical constituents of the tissues electrolyzed.

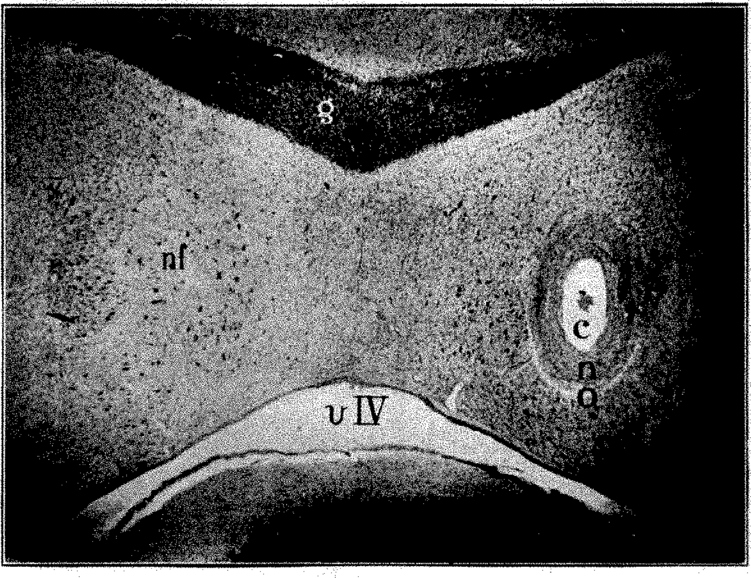

FIG. 15.

Anodal lesion made in the nucleus fastigii (outer group of cells) just before death. (Methylene blue.)

c Cavity of lesion.
n Necrotic zone.
o Œdema zone.
g Granule layer of a pyramid folium.
nf Nucleus fastigii. (Note [with lens] that the nerve corpuscles near the lesion stain more deeply and appear somewhat smaller than the normal cells on the opposite side, and that the layers of necrosed tissue exhibit concentric distension.)
vIV Fourth ventricle. (Dog.)

It is obvious that since as it has been shown that the conductivity of serum hardly differs from a 0·7 per cent. solution of NaCl, and that the rapidity of ionization in a gelatinous solution varies with the concentration of the latter (Leduc [8]), so the dissociation of the

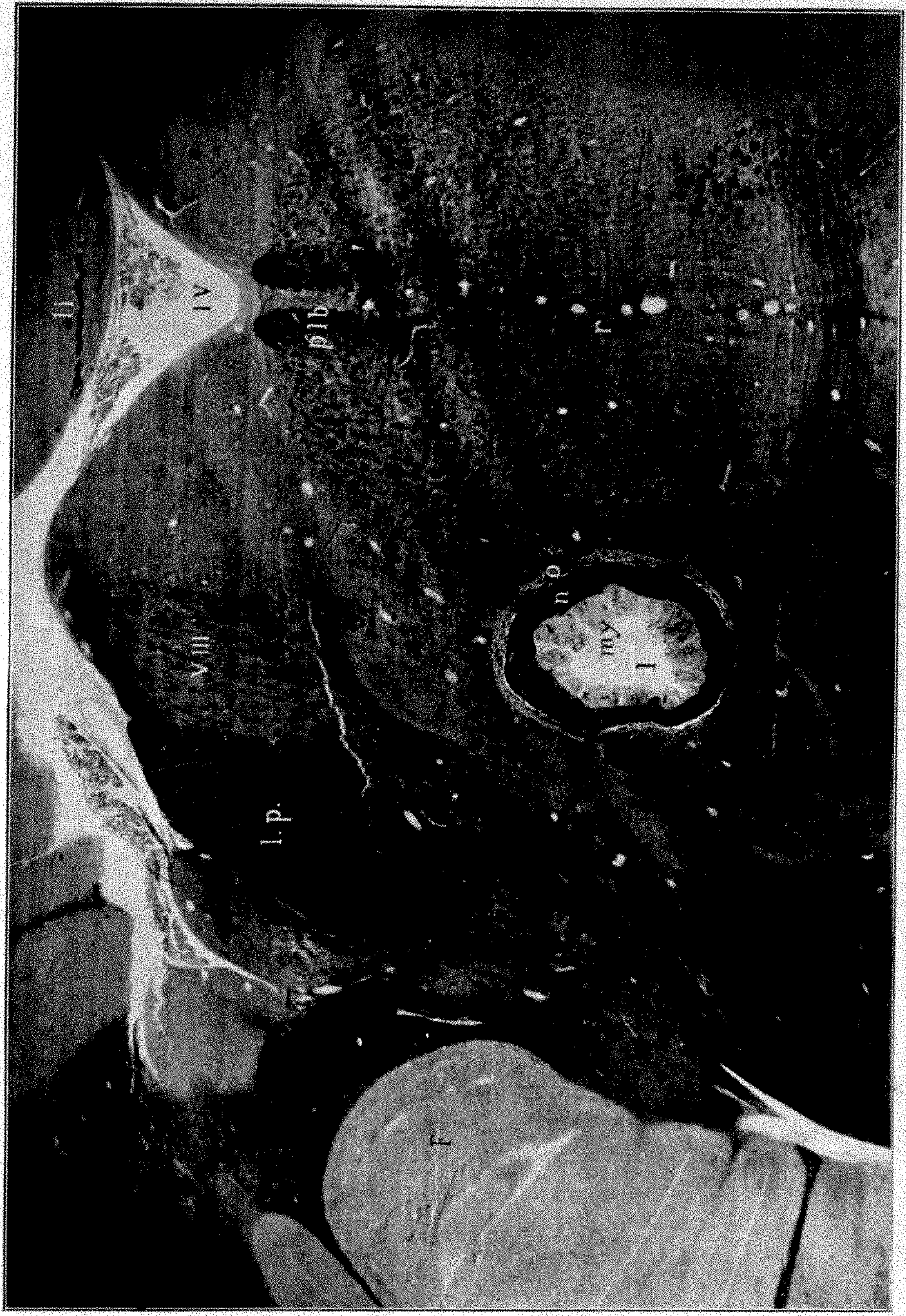

FIG. 16.

Anodal lesion, twenty-two days old, in the lateral region of the bulb. (Osmic acid.)

IV	**Fourth ventricle.**
VIII	**Descending vestibular tract.**
l	**Lesion cavity.**
li	**Lingula.**
l.p.	**Inferior peduncle.**
plb	**Posterior longitudinal bundle.**
r	**Raphe.**
my	**Columns of myelin. (Note their radial arrangement.)**
n	**Necrotic zone.**
o	**Œdema zone.**

cerebrospinal fluid of the blood and serum and of the neuroglia and nerve elements will proportionately differ and result in separation.

Our knowledge of this interesting phenomenon of convection, first demonstrated by Hittorf in respect of the greater velocity of the anion compared to that of the kathion, has been extended by Kohlrausch, who showed that if the kathion of different molecules remained the same the velocity would further vary according to the anion.

Finally, all investigators have shown that large complex molecules are more retarded than smaller ones.

From all these considerations it followed that a definite, if coarse, separation of the constituents of the nerve tissues might be looked for. Such is the case, and the centre of the lesions (*see* figs. 15 and 16) shows the complex fat-protein molecules as though left behind during the extension of the electrolytic processes; intermediately are the collagenous tissues, and furthest of all is a watery zone.

(*b*) *Distension.*—But in addition to this chemico-physical disarrangement by convection there is another mechanical effect which in our opinion is as powerful, and that is the distension or compressing effect of the gases developed in the lesion. These are present both in the anodal and kathodal lesions, but as for the same strength of current there is a greater volume of gas at the kathode than the anode, the mechanical destruction effected by the kathode is greater (in the proportion of 4 or 5 to 3) than that produced by the anode. In each case, however, there is an obvious disruption by the current of the tissues attacked and in each the pressure of the gas produces a condensation of the tissues as they are necrosed, this condensation resulting in the tissues being compressed concentrically with the axis of the lesion. This is exceedingly well shown in figs. 15 and 16, which represent respectively the condition of a lesion made (*a*) just before the death, and (*b*) three weeks before. When we first observed this mechanical distension effect of the gases and could not find that attention had been particularly directed to the point, we thought it was worth while to investigate the question a little further and to see how far destructive effects could be

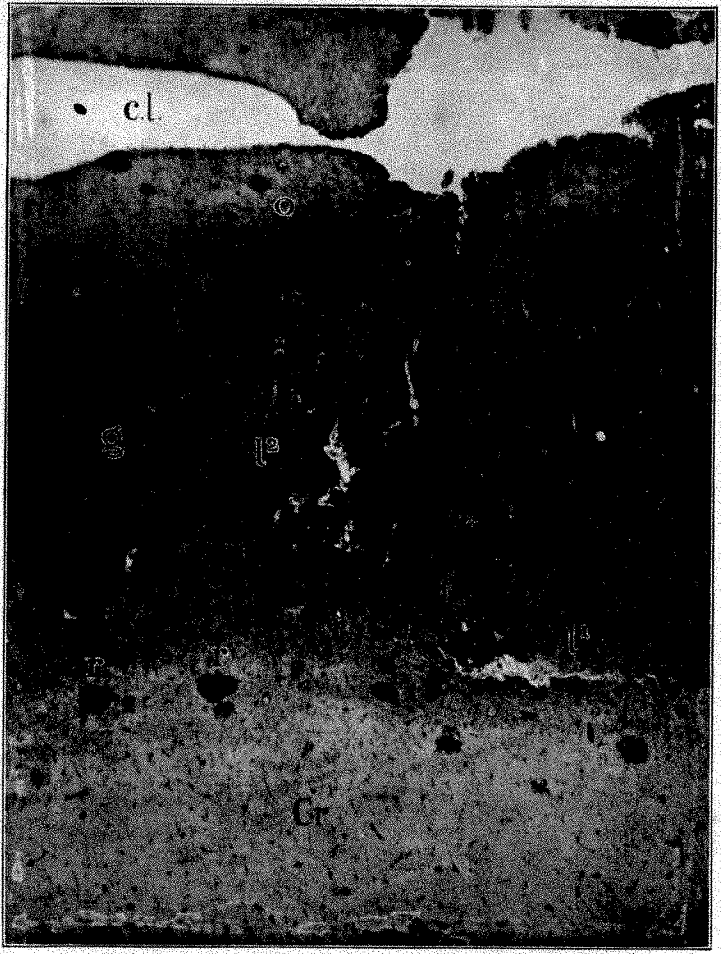

FIG. 17.

Experimental production of a lesion by injecting gas under pressure in water.

c.l. Central cavity of lesion.
o Œdema zone.
l^1 l^2 Lesions at a short distance produced by the gas and water following the perivascular lymphatics.
r r Thrombosed blood-vessels.
Cr Corona radiata.
g Section of the bottom of a sulcus, *i.e.*, grey cortex. (Dog.)

produced in living brain substance by gases under pressure and in solution. We therefore made sundry injection experiments, using hydrogen or carbonic acid gas and water under pressure. The result is shown in the accompanying photograph (fig. 17), from which it is evident that there are considerable effects even at a distance from the source of pressure and further that the mischief spreads because the gas and water tend to force their way into and dilate destructively the perivascular lymphatics.

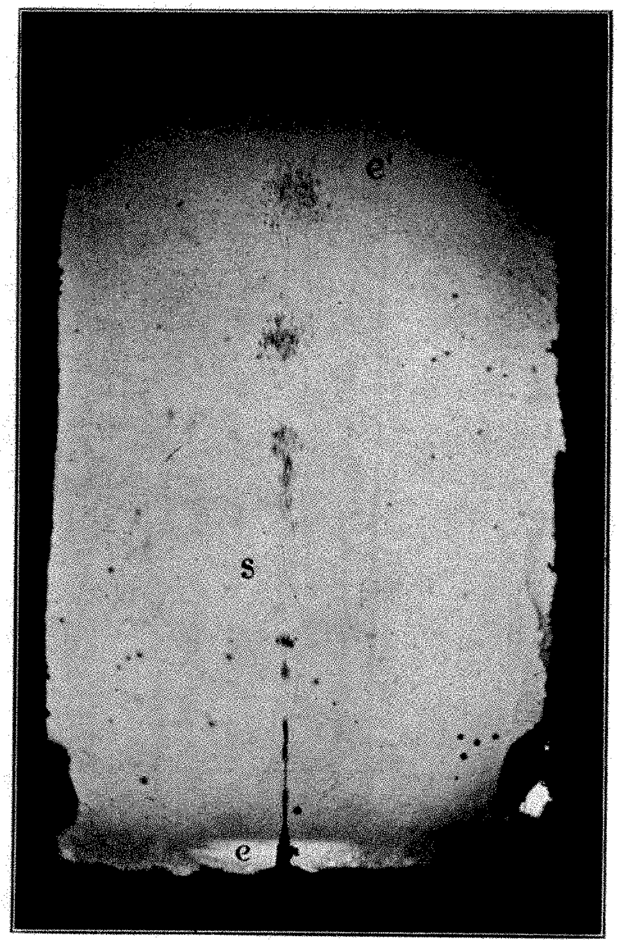

Fig. 18.

Instantaneous photograph of stream of gas, emanating from the point of the needle electrode, e, when it is a kathode. (The opposite electrode is just above, e^1.) The solution, s, is transfusion saline fluid containing phenophthalmein. The colour developed by the reaction is shown as streaks left by the ascending bubbles.

On this point, further, we have made comparative experiments with anode and kathode respectively to show, if possible, graphically a comparison between them when a moderate current (2 to 5 ma.)

is employed. For this purpose we fixed in a water cell, as shown in figs. 18 and 19, the positive and negative needle electrodes, and obtained, as seen in the instantaneous photograph, the proportionate amount of bubbles of gas developed by each. The character also of the evolution of the gas is seen to differ in the two cases, being more explosive and ebullitional from the kathode.

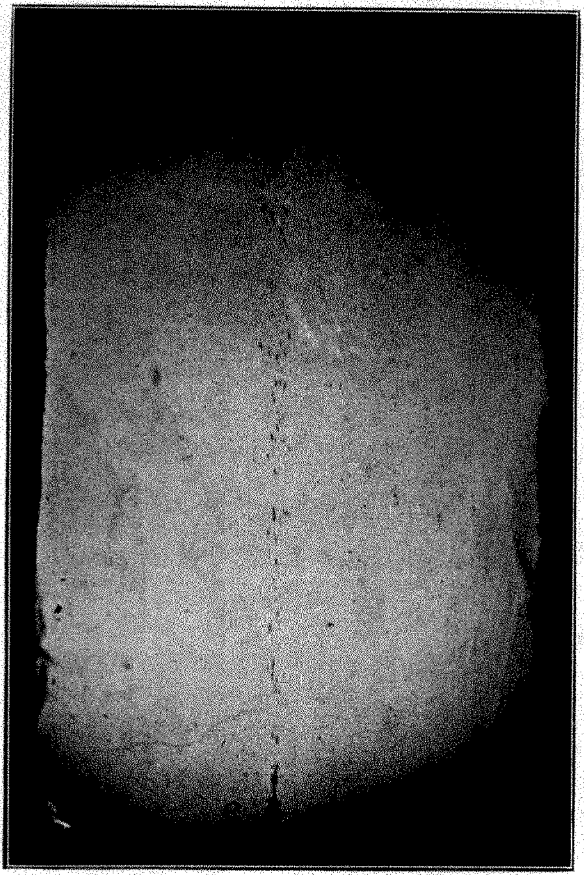

FIG. 19.

Similar photograph, showing the much less quantity of gas developed and with less ebullition when the electrode, e, is an anode.

(2) *Chemical effects.*—The first and most striking contrast between anodal and kathodal lesions is the reaction, the kathodal lesion

being strongly marked by deep blue, whereas the anodal lesion in the brain tissue simply bleaches litmus; but as Dr. Lane has shown with di-methylamido-azo-benzol there is outside the bleached point a ring of acid reaction.

The anodal lesion.—The histological changes in the anode are so characteristic and useful for our purpose that we endeavoured to ascertain what chemical effect was produced there. The anodal bleaching effect is due to the chlorine dissociated from the NaCl, and the particular form of anodal coagulation of proteins and tissues is attributed by Leduc and others to the combination of the chlorine with the water and formation of HCl. Dr. Gordon Lane, however, was unable to estimate in anodal lesions of the brain the exact quantity of the acid, though in a solution of saline electrolytes resembling the inorganic constituents of serum, he was able to make the estimation accurately.

The kathodal lesion.—The chemical condition of the kathodal lesion as estimated by Dr. Lane is that a definite amount of alkali is developed, but when we compared the degree of tissue destruction in the lesion with the trivial effect produced in a normal living brain by the injection at any given point of a similar amount of alkali it was obvious that the latter, whether nascent or not, could not be a practical factor in the production of the destructive effects.

(3) *Quantitative relations.*—On the question of the quantity of electrolytic destruction varying directly with the quantity of electricity employed, Dr. Gordon Lane has kindly made for us a very large number of titration experiments with electrolytic solutions resembling serum, the details of which will be published in full by him in this Journal.

The solution in the first set of observations was of two different degrees of quantity of electrolytes. Nevertheless, the same current, namely, 1 ma. for ten minutes duration, with a 23 gauge electrode, gave 0·00248 increase of alkalinity in the one, and the same current, time and electrode gave from the other solution 0·0026642, practically identical figures.

The next set of observations had relation to the duration of the application of the electrical current. In these the solution was electrolyzed for five, ten and twenty minutes, and the gain of alkalinity was respectively 0·0136, 0·00264, 0·00588.

It is evident that the relationship of time and quantity cannot be closer.

In Dr. Lane's third series of observations he compared different sizes and different lengths of the electrolytic needle; it was found that results practically true to the fourth figure were obtained, and showed that for constant current strength and duration the resultant gain in alkalinity was the same whether the electrode needle was fine or coarse, short or long.

A fourth table of great quantitative interest was the proportionate gain in alkalinity evoked by different milliamperage. The average obtained was as follows: 1 ma. gave 0·0012, 2 ma. gave 0·00248, 4 ma. gave 0·00488.

The last point of more special interest is the relative action of the kathode and anode. We have repeatedly drawn attention to the anatomical changes produced by the gas pressures, but these do not fully indicate that the volume of the gas liberated at the kathode exceeds so largely that derived from the anode. Thus, in one of Dr. Lane's observations, a measured volume of gas was evolved by the kathode in twenty-four and a half minutes, but by the anode in only 108; hence in this experiment more than four times the volume of gas was liberated at the kathode.

To sum up, the determination of the electrolytic products in a simple solution of electrolytes is a certain and accurate process, because the relationship between quantity of current and effect produced is also very definite.

For full discussion, however, of the points involved reference must be made to Dr. Lane's full paper.

The Size and Nature of the Lesion.

(*a*) *Size and outline of the electrodes.*—The size and shape of the lesion depends in the first place upon the size, outline and position of the electrodes.

Unipolar needle.—The most restricted globular lesions we have obtained by employing a unipolar needle with but 0·5 to 1 mm. of platinum exposed, the other "indifferent" electrode being formed by all the points of contact of the instrument (*e.g.*, the frame fixing screws, aural pivots, &c.) with the head, or by insertion in the wound, or by a large indifferent plate electrode applied to the body.

With such an arrangement and an extremely fine wire as the unipolar needle it is easy to obtain destruction limited to very small groups of cells or bundles of nerve fibres. On this question of limiting the unipolar lesion it is important to note that when the other electrode has been formed by the "live stop" or other termination in the wound it has appeared as though there was a certain extension of the electrolytic change along the track of the needle, the path of least resistance for the current, exactly as noticed in excitation experiments.

This also is demonstrated by the average shape of the lesion, especially when maximal currents are used and for a considerable time. Under such conditions the proportionate diameter of the lesion in the line of the axis of the needle to that at right angles is nearly as 2 to 1.

Bipolar needles.—Of the two forms of bipolar needles shown in fig. 12 that which we have called the concentric pattern produces a lesion the outline of which is a repetition of the form of the whole of the end of the electrode even when only the collar portion is employed, *e.g.*, as a unipolar anode. Similarly the other form of bipolar needle produces a lanceolate or flame-shaped lesion. It is thus quite clear that, as might be supposed, the area of nerve tissue which is damaged by the pressure of the point of the needle yields first to the necrosing effect of the current, and thus the shape of the electrode is of considerable importance for precise topographical limitation of the lesion.

(*b*) *Quantitative production of the lesion.*—In the second place the size of the lesion depends on the amount of the current employed. We originally hoped that we should be able to regulate the degree of destruction entirely in accordance with Faraday's law, and that the quantity of decomposition of the tissue would be directly proportional to the quantity of electricity employed (Arrhenius). In this we have only been partly successful, the reason being that the factor of time carrying with it also the alteration of resistance deprives the method of mathematical accuracy. We have, however, by accumulating a large number of experiments, been able to arrive at a clear understanding as to what is necessary to produce a given effect. On this point the diminution of resistance to which allusion has just been made must first be referred to. The readiness of living tissues to polarize has long been recognized, and the fall of resistance, which has been a striking and constant phenomenon in our experiments, is proportional to the ionization and coagulation obtained. It can be readily compensated, and by a sliding resistance we have thus kept the experimental condition constant as far as possible during the process of making the lesion. The quantity of electricity we have used (*i.e.*, milliamperage and duration of application), and especially in its first factor, which has varied during the last two years only between 1 and 5 ma., is much smaller than that employed by our predecessors, hence we cannot enjoy the advantage of comparison with their results.

Moreover the wide difference of effect according to the contrast in polar action such as we are about to describe has not been employed by other experimenters; this has influenced us so much in favour of the anode that any comparison between the size of the lesion and the quantity of electricity required to produce it ought in future to be considered as referring to an electrode used as an anode.

High milliamperage is wholly unnecessary; thus 1 ma. produces an adequate effect in a few seconds (fifteen) on a single group of cells, but 2 ma. give a more constant result, and a hyper-maximal effect is reached with 5 ma.

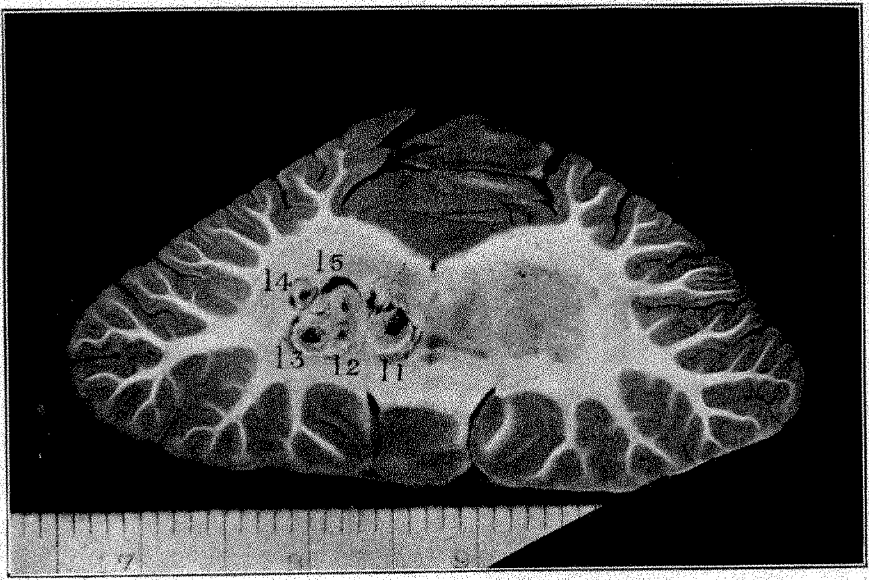

FIG. 20A.

Five anodal lesions, 11—15, made three weeks before death to destroy the nucleus dentatus, embolus, globosus and outer part of nucleus fastigii. (Note that the lesions have been made by successive insertions of the needle, and that the object of the procedure is attained with minimal injury to surrounding parts. The smaller scale divisions are millimetres.) (Macacus rhesus.)

Next, as regards the influence of time, which must be considered directly with that of milliamperage, our experience has been that although a notable effect is produced within a few seconds, the amount of further destruction proportionately diminishes as the time is prolonged. We have not, however, worked out any definite curve of this diminution, but in a number of preliminary observations we found

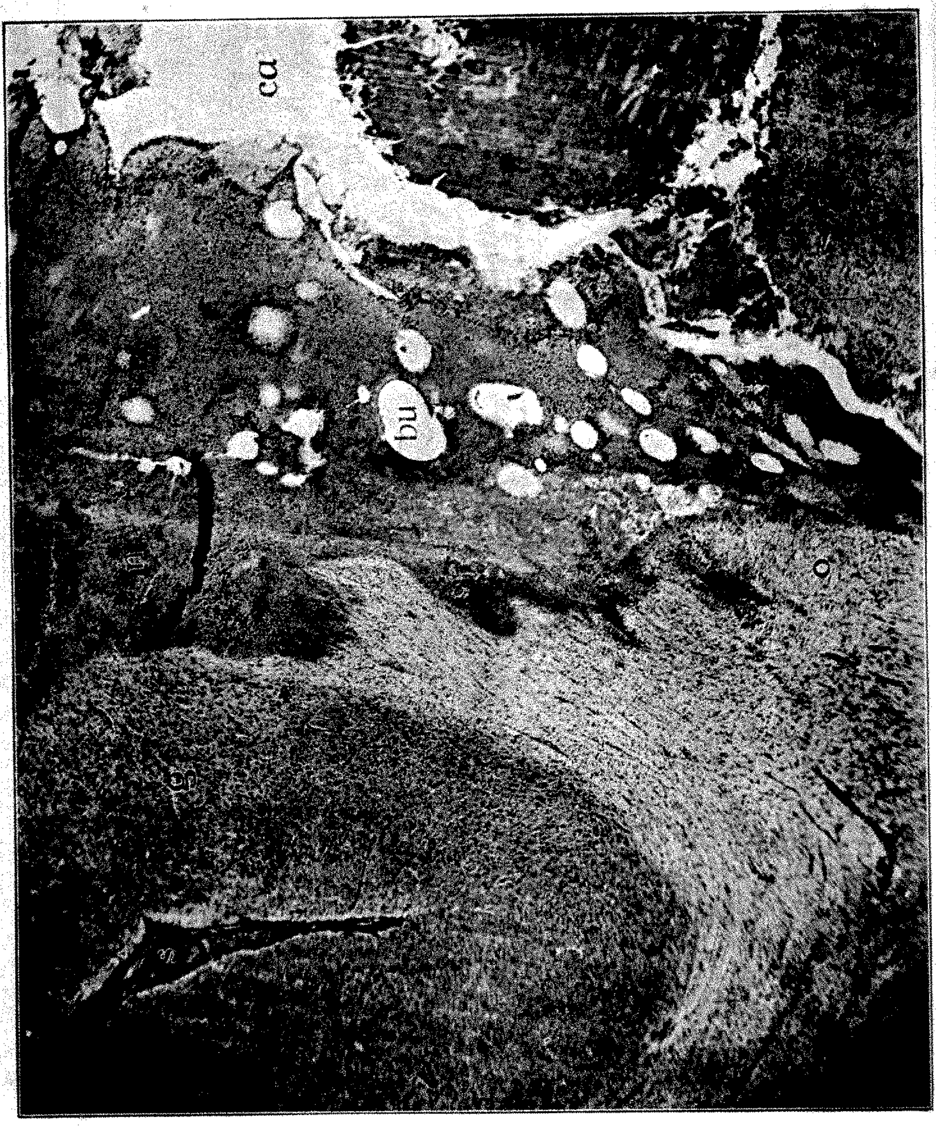

FIG. 20.

Margin of a large kathodal lesion made just before death.

ca Central cavity of lesion. Below the letters is a large mass of necrosed tissue and clot. To the left is the advancing necrotic border, n, showing numerous gas bubbles, bu, and largely consisting of altered, *i.e.*, electrolyzed, blood-corpuscles.

o Œdema zone.
g Normal gyrus.
s Normal sulcus.

that it was so marked[1] as to render any increase of the time above five minutes purposeless. For practical purposes a rough average of quantities and proportional effects may be drawn up as follows :—

Kind of lesion.	Size of lesion.	Quantity of current.	Duration of electrolysis.
Simple anodal lesion ...	2·7 mm. ...	3 ma. ...	1·8 min.

Combining many observations together it is evident that for a unit of time, *e.g.*, one minute, there will result about 1 mm. breadth of destruction for each 1 ma. of current employed. This, of course, is only approximate, and only true within about 5 ma.

We will next describe the structural changes wrought in the cerebral and cerebellar tissues by the electrolytic processes.

Macroscopical Anatomy of the Lesion.

From what has been already stated it will be realized that, whether anodal or kathodal, the lesion presents three zones on naked-eye examination, *i.e.*, a central cavity (containing gas, watery fluid, myelin, &c.), a zone more or less broad of necrosis, and outside that a narrow zone of œdema. All these three zones are extremely obvious within a month after the lesion is made, but we have not yet examined the ultimate fate of the lesion after longer survival periods. To the naked eye the differences between the polar effects are very obvious and coincide with the descriptions given of and results obtained by electrolysis of the blood. Thus the anode produces a small central cavity surrounded by a compact greyish pink coagulation or necrotic area; the kathode causes, on the contrary, the production of a larger cavity filled with a rosy pink fluid, often almost gelatinous in its viscosity, the walls of the cavity showing the presence of bubbles of gas and consisting of necrosed tissue, which is whitish yellow, soft and diffuse. These differences are shown in the accompanying photographs, figs. 20, &c.

Similarly the œdema border around the kathodal lesion is proportionately wider than that bordering the anodal injury.

Microscopical Anatomy of the Lesion.

The microscopical details of the changes produced are of the highest importance, and especially because they show at once the great advantage of this method of making experimental lesions, namely, that the injury produced is sharply delimited from the surrounding tissues, and consequently the loss of physiological function is strictly confined to the seat of electrolysis. As a side fact, a physiological proof of this may conveniently here be stated. It is that when, during an excitation experiment, a restricted electrolytic lesion has been made to mark some spot from which a definite response has been obtained, we have found, on advancing the needle another millimetre, that the uninjured tissue immediately adjoining is normally excitable.

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[1] As an example we may quote the figures obtained from an experiment on this point, as follows: Needle, 22 gauge; amount exposed from glass sheath, 2·5 mm.; place, dentate nucleus; pole, kathode; amount of current, 5 ma.; duration, thirty minutes; result, lesion 8 mm. in line of needle; 6 mm. at right angles to same.

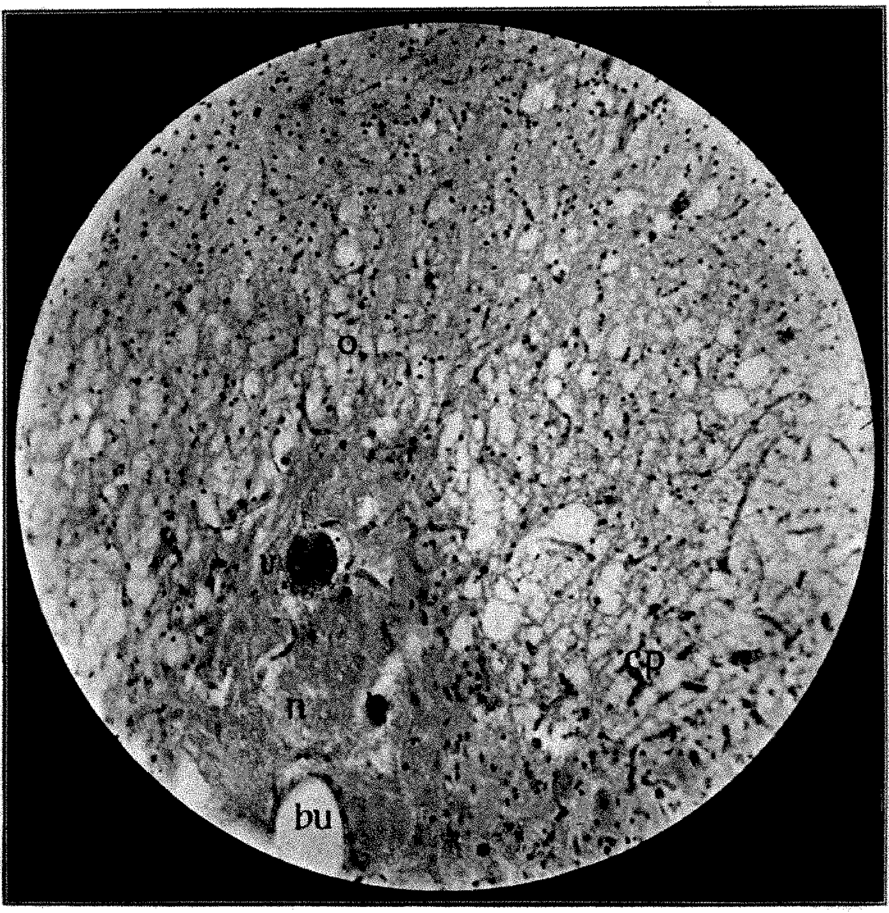

FIG. 21.

Section of margin of kathodal lesion made just before death, showing the dissociation of the neuroglia by the gas and fluid forming the œdema zone, o; the edge of the necrosed tissue, n; a gas bubble, bu; congested capillaries within which thrombosis has occurred in some, cp.

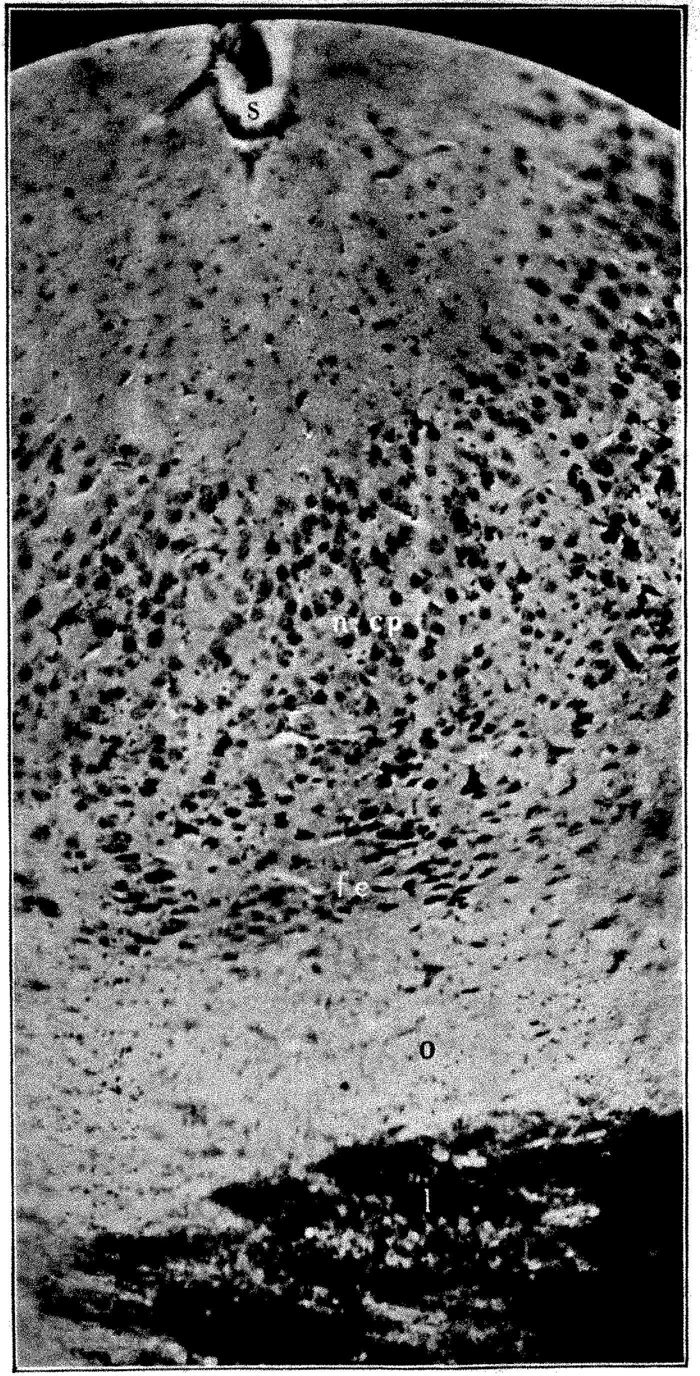

FIG. 22.

Vertical section of gyrus and kathodal lesion just below it, l, made just before death. The lesion shows laked blood and numerous very small gas bubbles. The œdema border, o, extends to the cortical layers of cells, of which the lower layers, fe, are flattened by the gas pressure, whereas the upper layers, n. cp, are normal; s = bottom of a sulcus. (Cat.)

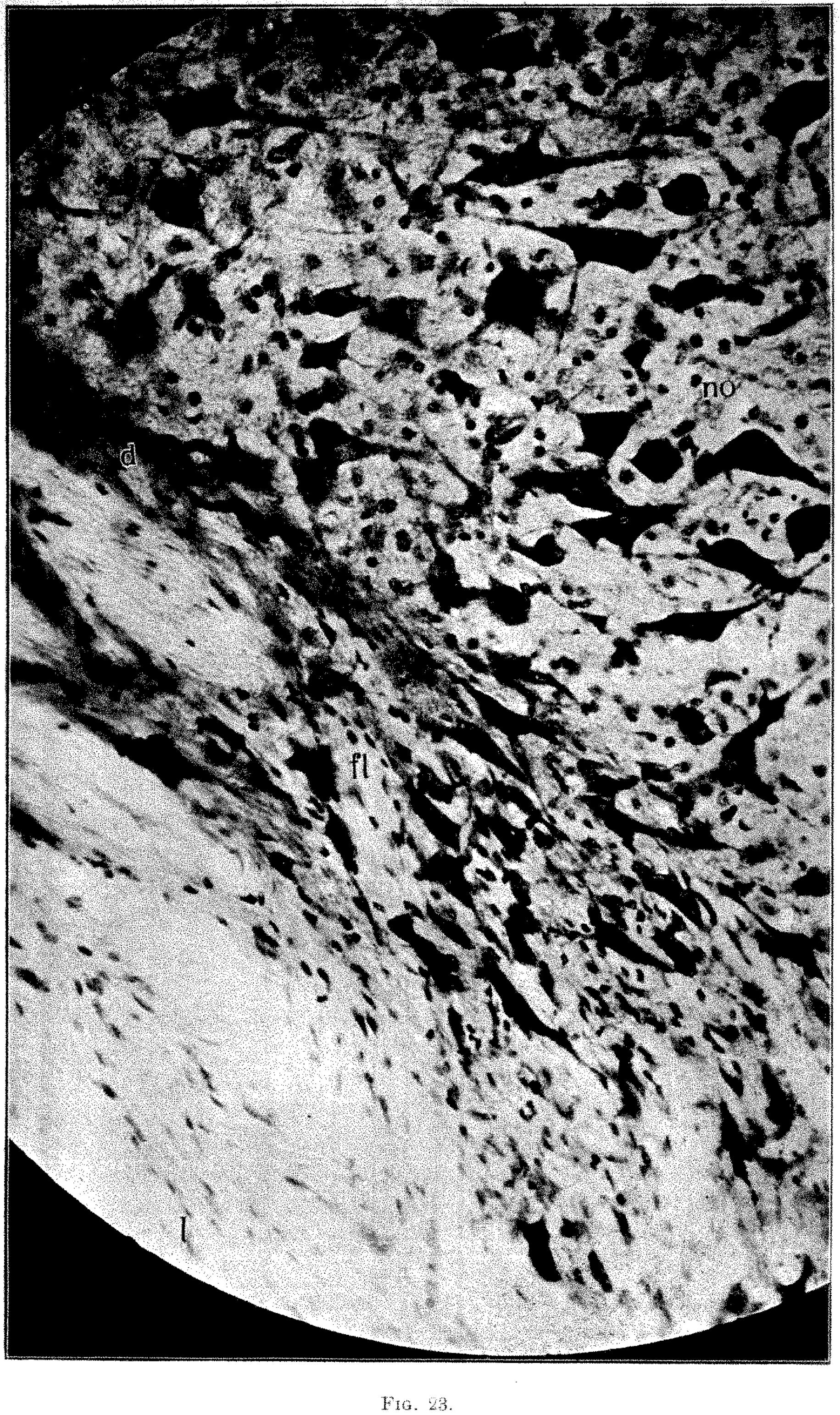

FIG. 23.

Margin of an anodal lesion made just before death in the bulb close to the motor nucleus of the fifth cranial nerve, no, showing the compression and destruction effects of the electrolytic lesion on a portion of a nucleus. The neuroglia, partly in solution, is shown at the bottom left hand corner at l. The nerve cells involved are seen flattened and distorted at fl, whereas the cells in the rest of the nucleus, n o, are still functionally active.

To proceed now to the details of the microscopical changes observed, we can most conveniently condense the large amount of material we have collected by grouping the facts under two heads: (1) lesions created just before systemic death; (2) lesions created three weeks before death.

The second class naturally only presents as additional features the phagocytic processes of removal of the necrotic tissues and products, as well as certain stages of commencing repair.

(1) *The Histology of the Electrolytic Lesion when Made just before Death.*

Although the first and principal change in the entire living brain is the electrolysis of the blood and lymph, the nerve tissues begin to break down very soon, and the fate of the different components may be taken separately.

(*a*) *Changes in the neuroglia.*—The changes in the neuroglia must be considered according to the degree of destruction.

(1) *Zone of necrosis.*—The nuclei of the neuroglial cells rapidly lose their capacity for staining with basic dyes, though the nuclei of leucocytes still stain readily.

Similarly the neuroglia fibrils refuse to stain, and in differentiating polychrome methylene blue stained sections the compressed nerve tissue (which subsequently necroses) decolorizes before the normal from which it is sharply marked off.

Before disappearing the nuclei become distorted and shrunken, though for a long time their outlines or nucleolar contents can be recognized in the necrotic coagulum. The fibrils and "punkt-substanz" of Retzius become fused into an amorphous mass, which under a high power looks like a coagulated precipitate, but is notably denser than the precipitate in the cavity of the lesion, which is certainly altered blood-plasma and has a loose floccular and granular appearance.

(2) *Zone of œdema.*—In the zone of œdema which immediately surrounds the necrotic core and separates it from the normal surrounding tissue the meshes of the neuroglia are simply torn open, thus forming spaces. The stages by which this is produced are seen in the photograph, fig. 21, where the small holes showing themselves in the section bear a relation to the cell spaces of the tissue generally, and, moreover, are exactly similar to the small cavities produced by the injection of hydrogen into the cerebral tissue.

The nuclei of cells of the all connective tissue type become granular, the protoplasm of the body of the cell ceases to stain, the nuclei begin to shrink, and as they shrink often take the dye excessively and appear almost as black points.

A coagulation precipitate (exceedingly fine) can be seen between the fibres forming the œdematous border of the tissue which is necrosing and which will form the zone of necrotic tissue.

(*b*) *Changes in nerve cells.*—The earliest change is a general fusion tigrolysis. The cell bodies stain darkly, ultimately intensely darkly, and then proceed to shrink, the contraction naturally being most marked at first between the dendrites.

This general change applies to all nerve cells.

The details of the change merit further investigation. As far as we have seen the tigroid bodies first contract and the intervening cell substance tends to stain diffusely.

With the shrinking of the tigroid body (which renders it very narrow in longitudinal section of the cell and point-like in transverse section) there is also intenser coloration of it.

While this alteration is proceeding in the body of the cell the axone and dendrites are undergoing a disappearance of fibrillar structure followed by swelling and paling, and this again by shrinkage and deformation.

The cells thus degenerating in the zone of necrotic compression also show very interesting mechanical defects by torsion, especially in the large dendrites and axone (*see* fig. 23).

Further, by reason of the contraction of the tigroid bodies, spaces like vacuoles appear in the protoplasm of the cell, and often are strictly circular in outline as though holding fluid. In many instances the remaining chromophile substance is aggregated at the border of the cells, in others more rarely round the nucleus.

The nucleus does not move towards the side of the cell, but as it shrinks it becomes more deeply stained and shrivelled on the nucleolus until it stands out in sections as an intensely dark point.

(*c*) *Changes in nerve fibres.*—Nerve fibres attacked by the electrolytic process are apparently simply dissolved. In accordance with the like changes in the connective tissue protoplasm the axis cylinders within the neurotic zone refuse to stain with polychrome methylene blue, but they can readily be distinguished and particularly as they do not swell before disintegration.

The myelin of their sheaths flows in the liquid in the lesion cavity as the fibres undergo dissolution. Indeed, in some preparations (*see* fig. 16, 25) it appears as though the compression of the necrotic zone by the gases in the cavity caused the myelin to ooze out and be left in trails radiating from the centre of the lesion, *i.e.*, arranged in columnar fashion as though along lines of electrolytic convection.

The fate of the myelin will be discussed later, but attention should here be drawn to the fact that as it escaped from the fibre sheaths it is but little altered and consequently it gives to osmic acid practically the same reaction stain as a normal fibre.

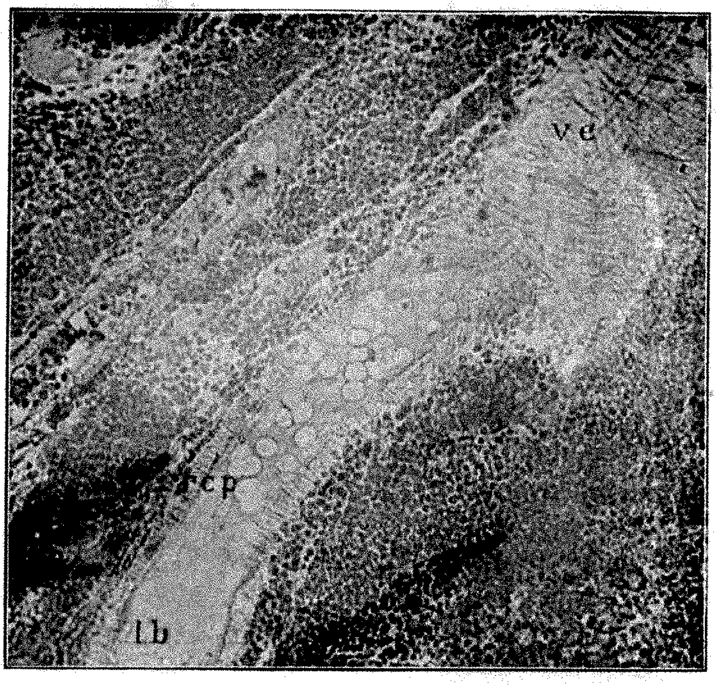

FIG. 24.

Electrolytic changes in a vein and blood. Kathodal lesion.

v e Vein wall undergoing dissolution.
r c p Stromata of red corpuscles swollen and lying in blood, which is completely laked at l b. Surrounding the vessel are shrunken blood-corpuscles, h g, lying in the cavity of the lesion.

In summary it may be said that the alteration of the nerve fibres indicates the destruction to consist of a progressive solution, so that there is practically little interval between the disappearance of the structure and the complete fibre.

(*d*) *Changes in the blood-vessels.*—The altered condition of the blood-vessels first evinces itself in the immediate neighbourhood of the lesion by thrombosis of the smallest vessels. The blood slightly coagulated shows no change in the corpuscles.

Later, the muscle fibres in the wall of the vessel undergo a cloudy swelling metamorphosis and then show considerable hyaline changes. A vessel in this condition is often seen hanging in the lesion cavity and undergoing at its free end a solution of its elements. Such a vessel while intact contains a thrombus consisting of altered corpuscles, but as the next result of the electrolytic process is a liquefaction, such thrombi are very fragile and partial.

The dissolution of the elements of the vessel wall is not without interest, as the most resistant are the endothelial layer and elastic lamina, and further because there is a very short stretch between the point of complete destruction and that of a fairly complete vessel.

(*e*) *Changes in the blood.*—The changes in the blood commence with the dissociation of the red corpuscle in the manner indicated by Brücke forty years ago. The pigment holding protein compound (Brücke's zooid) escapes from the stroma and consequently aggregations in the neighbourhood of the lesion of partly decolorized stromata within the vessels are a characteristic feature of the electrolytic process. Such stromata stain a greenish purple with polychrome methylene blue.

This results in an early laking of the blood, and the decolorized stromata soon become invisible in the highly tinted plasma. Nuclear stained sections often show the vessels containing thoroughly laked blood in which are floating practically unaltered leucocytes (*see* fig. 24).

The next stage affords a highly interesting instance of convection, for the colouring matter (protein compound) is carried through the wall of the vessel and collects in nodular masses, leaving the contents of the blood-vessel evidently little more than water, as there is frequently no protein precipitate in it.

The blood in large vessels passing through the lesion affords interesting points for study of the corpuscles apart from the convection phenomenon above mentioned. The red corpuscles become crenate and irregularly shrunken, showing bright particles of hæmoglobin without arriving at the later stage of hæmosiderin, but granules of the last-named substance are seen in quantity in the *débris* in the lesion.

(2) *The Histology of the Electrolytic Lesion Three Weeks After.*

The chief differences between the lesion immediately examined and that in which the animal has been kept alive three weeks before death are essentially summed up in the word phagocytosis, for all the conditions as just described are present, namely, the necrotic zone, its central cavity and the zone of œdema. We will therefore begin with the phagocytic cells (*see* fig. 25).

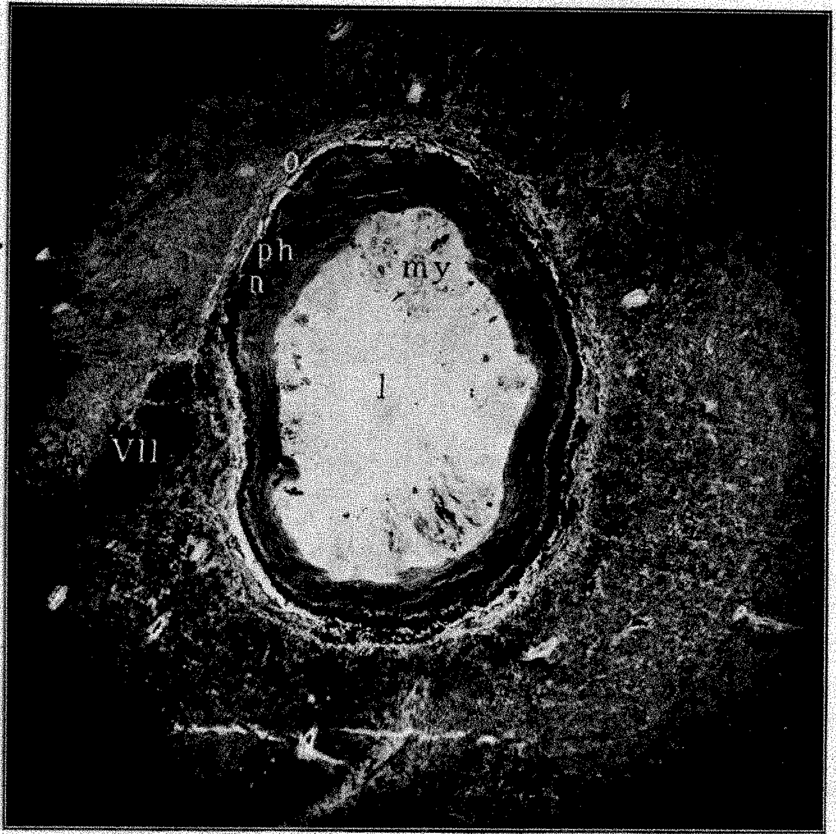

FIG. 25.

The lesion, made three weeks before death, in fig. 16, more highly magnified.

1 Cavity of lesion, containing a few leucocytes and much myelin in radiating columns, my. The necrosed tissue, examined with a lens, shows well the distension effect of the gas content of the lesion. The dense black ring of phagocytes, ph, closely surrounds the necrosed tissue and the two other subzones of the œdema zone, o, are well marked.

VII The seventh cranial nerve totally degenerated, being divided by the lesion.

(1) *Distribution of phagocytes.*—A very interesting characteristic is noticed where a restricted globular lesion has been made deep in the substance of the organ and where consequently the wall of necrosis is unbroken. It is then seen that though the phagocytes are thickly aggregated in the œdema zone they nowhere succeed (within twenty-five days) in

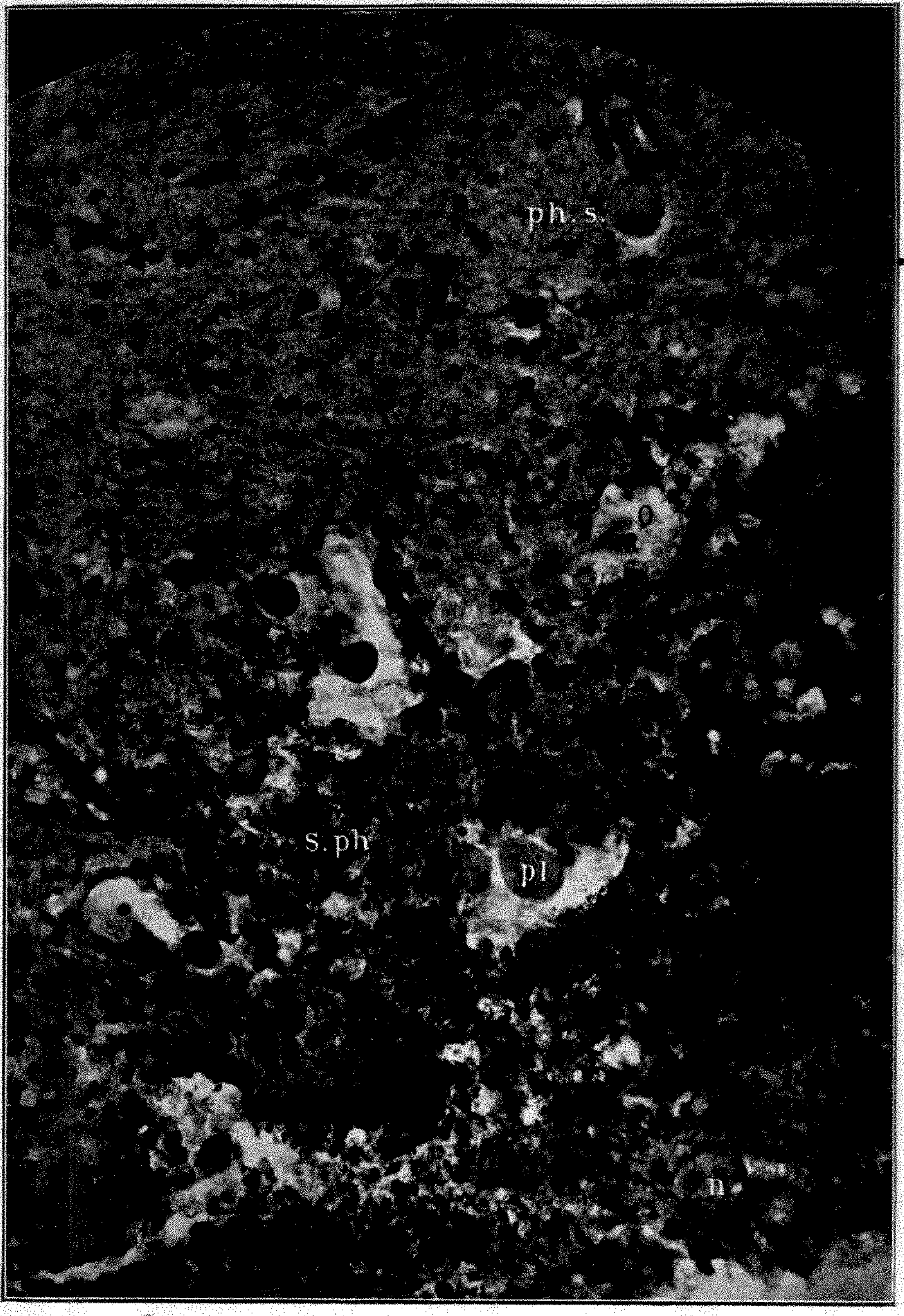

Fig. 26.

Section (methylene blue) showing the margin of a kathodal lesion made four days before death.

ph.s, indicating the genesis of a large phagocyte, is placed on the normal neuroglia at the extreme border of the œdema zone.

O is placed in the middle subzone in a (watery) space.

S.ph marks the line of phagocytes, the innermost subzone.

p l is a large phagocyte abutting on the necrotic tissue which lower down is marked n. (Dog.)

penetrating the necrosed tissue or coagulum or gaining the cavity of the lesion. The few stray cells occasionally met with on the inner side of the wall are obviously surviving leucocytes. On the disputed question of the genesis of Gluge's corpuscles it is interesting to note that these scattered cells only take up a few particles of blood-pigment or very little myelin. They are not comparable, therefore, with the ordinary phagocyte or Gluge's corpuscle. Consequently the distribution of the phagocytic cells

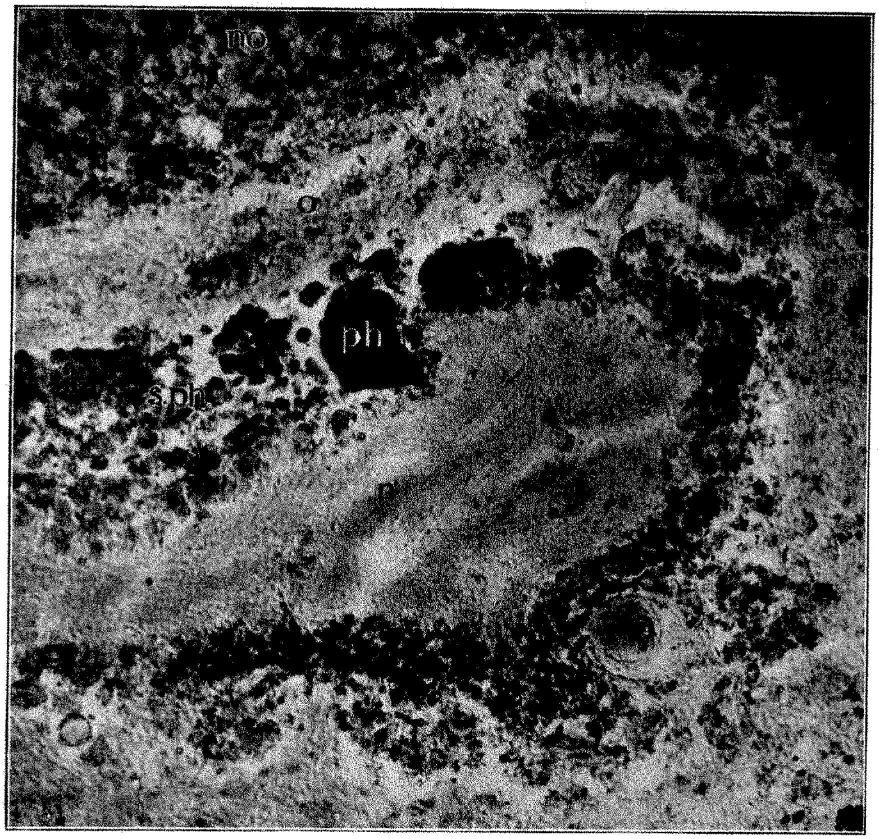

FIG. 27.

Margin of an anodal lesion twenty-two days old, showing the subzones of the œdema zone and the two classes of phagocytes.

n Necrotic tissue.
S.ph Innermost subzone, containing many small phagocytes.
o Middle œdema subzone.
ph Giant phagocytes
n o Outermost œdema subzone, showing now only infiltration, with small granules stained black by osmic acid. All the phagocytes are full of such granules. (Macacus rhesus.)

(the true Gluge's corpuscles) in the œdema zone is extremely easy to map out.

For this purpose the œdema zone may be divided into three concentric zones: an innermost, a middle and an outer subzone (*see* figs. 25 and 26).

(*a*) The innermost subzone consists of a layer of phagocytes arranged column-wise in three or four concentric rows, but closely packed together and full of fine granules staining intensely black with osmic acid.

(*b*) The middle subzone is a watery layer in which float phagocytes and neuroglial *débris*, half destroyed vessels, blood partly clotted in various stages of absorption, myelin droplets, &c.

(*c*) The outer subzone contains very few phagocytes, but consists of the slightly affected edge of the normal tissue, that part of the œdema zone in which from the first a fine precipitate can be seen in the meshes of the neuroglia.

(2) *The character of the phagocytes.*—The shape, arrangement and contents of the cells differ in the three subzones, and may best be described *seriatim*.

(*a*) *Innermost subzone.*—The phagocytes which attack the outer surface of the necrotic coagulum resemble plasma cells in every particular. As a rule they are small, narrow and club-shaped, owing to their radial and packed arrangement in the œdema zone. At points in this ring of phagocytes giant-cells appear and many intermediate shapes, but the large protoplasmic masses, though staining a very dark brown, rarely contain more than a few granules (*see* fig. 27). The smaller the cell as a rule the more completely is it filled with myelin granules, obscuring the nucleus. In some the granules fuse into two or three large vacuoles filled with feebly staining myelin.

(*b*) *The middle subzone.*—In this layer, which is the true (separation) line of the necrosed tissue, we find large spaces filled with clear fluid or altered blood; the phagocytes floating freely are, as a rule, spherical in outline (*see* fig. 28). These are comparable to those found in extensive ischæmic softenings in man (*see* fig. 29).

(*c*) *The outer subzone.*—Running outwards from the edge of the œdema cavity are degenerated fibres which arose from the nerve cells destroyed by the lesion or are the peripheral portions of those which have been severed. The neuroglia between them is no longer water infiltrated, but there is a fine granular precipitate, which stains brown with bichromate of potash and osmic acid, as well as numerous fine black granules.

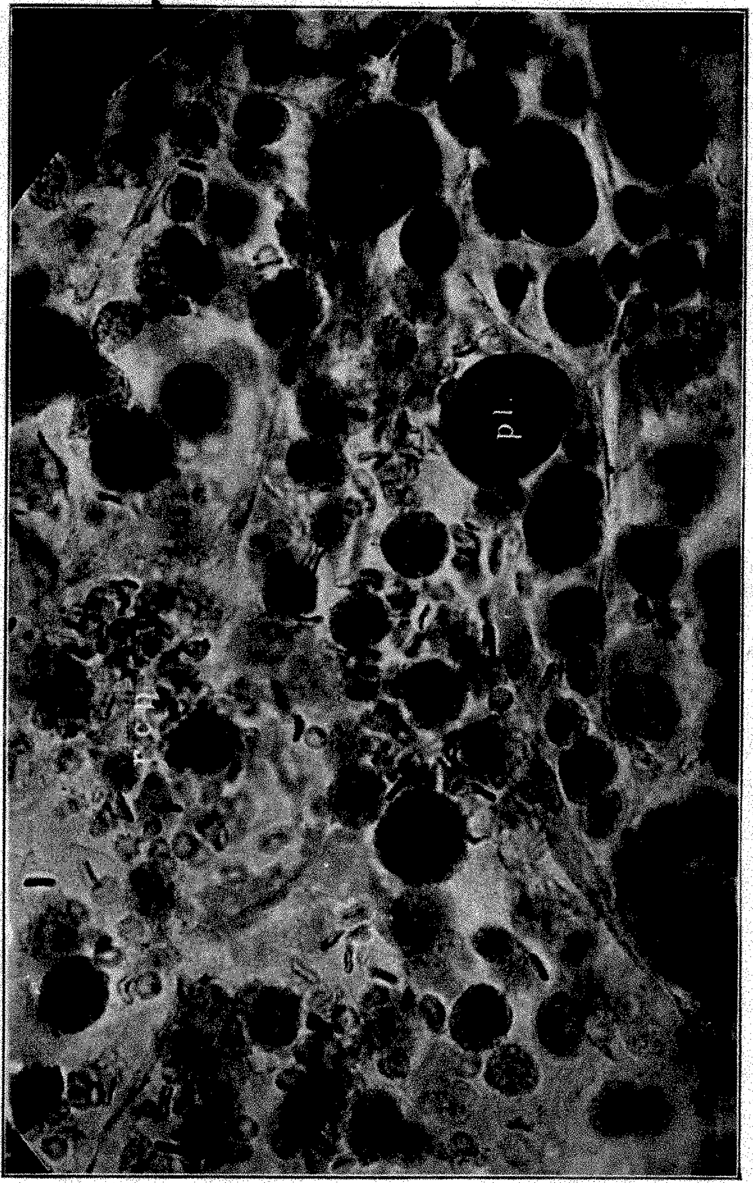

FIG. 28.

Phagocytes in an anodal lesion on the border of the fourth ventricle.

All the phagocytes contain many granules, which stain deeply with osmic acid. The large cells, p l, do not take up the red blood-discs, however altered. Of the red corpuscles, r c p, many still preserve a normal outline. (Macacus rhesus.)

V.—The Method of Excitation.

The systematic investigation of the functions of the cerebellum by the excitation method has been attempted by relatively few observers and only of the cortex cerebelli. The first was Ferrier [1], who employed the faradic current, and explored the cerebellum in different classes of animals. He was followed by Hitzig, Nothnagel and Dupuy, the first of these using the constant current, the latter mechanical irritation, which had already been attempted by Leven and Olivier and Weir-Mitchell. In later years, Sherrington, Löwenthal and Horsley, and

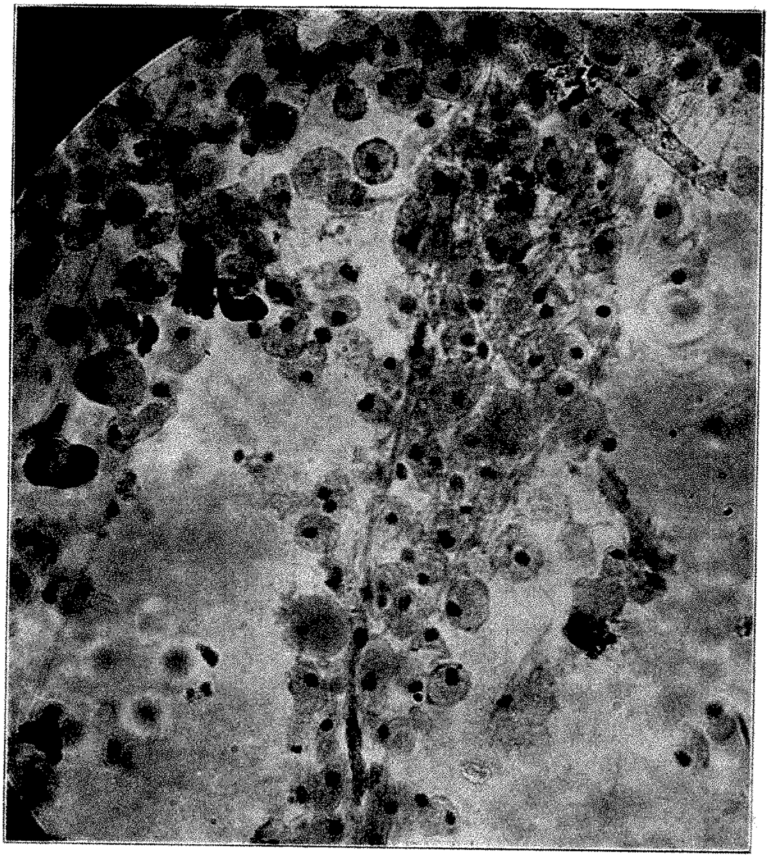

Fig. 29.

Phagocytes (Gluge's corpuscles) large and medium size, from a cerebral ischæmic lesion, to compare with fig. 26. (Man.)

Rijnberk, Lewandowsky, Pruss and Lourié have contributed short communications on the subject.

We will refer to the results obtained by those observers later in our second paper and here only discuss the following points of practical interest, which appear to us to govern the whole subject, and which certainly afford a test of the value of any particular method of investigation. These are:—

(1) Excitability of the cortex cerebelli.

(2) Relative excitability of the cortex cerebelli compared to that of the cortex cerebri.

(3) Relative excitability of the cortex cerebelli compared to that of the nuclei cerebelli and efferent tracts therefrom.

With the means described in this paper the functions of all these parts can now be adequately examined and differentiated, provided that some general principles are fulfilled.

(1) *Excitability of the Cortex Cerebelli.*

We begin by raising a fundamental question, viz., whether the cortex cerebelli is strictly speaking excitable to electrical stimuli. Ferrier records that in his experiments, using the interrupted current as stimulus, he obtained positive results in but a relatively small proportion of experiments, and to those who, like Nothnagel (*cf.* Pagano), employed a mechanical stimulus, viz., a needle point (sometimes heated), negative results were extremely common.

The explanation commonly given of these facts is that the difficulty of the operative procedure for exposing the cerebellum causes shock effects to the delicate cortex from loss of blood, &c., and so lowers its excitability.

We may most conveniently dismiss now this question of hæmorrhage and what is, in our opinion, the equally important matter of cooling. Though these adverse conditions have evidently occurred very frequently in previous researches on the cerebellum, they can be completely avoided by suitable care in operation, *e.g.*, by careful study of the situation and grouping of the blood-vessels, the use of lenses,[1] reflected illumination, constant irrigation with warm saline solution, large hot water trough support, &c., and finally by the instruments and topographical methods already described.

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[1] For exact adjustment of the apparatus used we have found magnifiers, as very kindly arranged for us by Mr. Henderson (viz., Sp. +7 combined with prisms +6 and fixed in a strong spectacle frame carrying mesially a concave mirror), quite essential. All the blood-vessels are strikingly revealed by such glasses and the topographical identification of any spot which has been determined by measurement is rendered easy.

Given all the operative conditions just stated, the negative results obtained by previous observers are, in our opinion, the genuine expression of what we have found to be characteristic, namely, that the cortex cerebelli is relatively inexcitable. This, of course, raises a new issue regarding the cerebellum, and we will now proceed to discuss the evidence in our possession. The first factor to be considered is the kind of stimulus employed. We will take the various methods and procedures which have been tried and begin with the less exact.

(*a*) *Mechanical stimulus.*—The cortex cerebelli itself has not been carefully examined with mechanical excitation, but Leven and Olivier, Weir-Mitchell, Hitzig, Nothnagel, and Dupuy have stated that mechanical puncture of the cerebellum sometimes causes movements which other methods suggest may be represented in the organ, but whether in the cortex or nuclei was not in the minds of these authors. Dupuy observed in addition to movements definite indications of algesia.

On this last point our observations are not strictly parallel, as they have all been made on anæsthetized animals, but as regards the question of mechanical excitation during the insertion of the insulated needle we have noted very exceptionally distinct motor effects which we believe are due to excitation of the subjacent nuclei or efferent paths from them. But though an effect may be observed to follow a puncture or slight stab of the cerebellum, that does not afford any proof that the cortex cerebelli as such has been excited, since every puncture of necessity involves the subjacent fibres, and in many cases the nuclei also.

The immediate effects observed by Pagano with injections of curare are similarly explicable and do not, we think, admit of interpretation as restricted and localized stimuli. Indeed, Pagano recognizes that the cortex cerebelli is very resistant to excitation, and that the general effects produced by his method are of diffuse origin is proved in his demonstration that excision of the opposite excito-motor cerebral cortex abolished the results.

(*b*) *Constant current stimulus.*—Hitzig found that the cerebellum (*i.e.*, as a whole) was definitely excitable to the constant current, but he naturally at that period did not discuss the present question of how far the motor response is ascribable to the cortex. In accepting his facts we cannot but deduce from our own experiments that there is a very sharp contrast between the reactions of the cerebrum and cerebellum to a galvanic and faradic stimulus respectively. The "shock" character of the galvanic excitation ("make" and "break") renders this mode of stimulation applied to the central nervous system much less precise than the faradic current in differentiation of reaction.

In fact, Hitzig's interesting observation that when by stimulating the "upper lobes" skew deviation of the eyes resulted, the direction of such deviation was reversed with the reversal of the current, seems to us to show that the excitation effect was not limited to the spot of application of the cortical electrode. Our own observations lead us to believe that as a stimulus the constant current cannot be ranked for accuracy and limited localization with the induced current, and further, that no proof is yet to hand that the cortex cerebelli has been excited alone in any experiments so far published.

We have during the past three years accumulated a large number of facts on excitation with the constant current in comparison with the interrupted current, since by our method when we proceed to mark by electrolysis a spot which has just given a certain response to faradic stimulation we cause both an opening and closing effect on the same tract or nerve centre as the case may be.

The results have fully borne out the foregoing statement as to the disadvantages of the constant current excitation, and especially its diffuse and shock-like effect. We need not, therefore, dwell further on this point, but turn to another interesting phenomenon which we have also observed and which appears to us to be explained simply as another form or demonstration of the principles of complex representation of Hughlings Jackson and of reciprocal innervation of Sherrington.

It is that if a definite motor response, *e.g.*, flexion of the elbow of the same side, is evoked by faradic stimulation of the dentate nucleus the antithetical or reciprocal movement, *e.g.*, extension, will be the response to galvanic excitation.

An indication of the same phenomenon we have also occasionally seen while employing the same (*e.g.*, faradic) stimulus if the nuclei are fatigued, and when contractures have already set in.

This is a further instance of the special modification of a motor response, as one of us (V. H.) showed ten years ago, for spinal centres [5].

(*c*) *Interrupted current stimulus.*—We have followed Ferrier in employing the faradic current as the most reliable stimulus (furnished by a Kronecker coil with one or two Obach dry cells in the primary circuit), and we have used it both by bipolar and unipolar application.

Our final conclusion is that though the cerebellum, *i.e.*, cortex and nuclei, *as a whole* responds to the faradic stimulus the presumed excitability of the cortex cerebelli is extraordinarily low compared with that of the cortex cerebri and that, comparatively speaking, the former is inexcitable. Further, that, as will be seen presently, the values obtained for different depths of insertion of the electrodes show not only that the cerebellar cortex is not directly excitable, but the cerebellar nuclei are, and to a high degree. The preliminary point of difference in the character of the effect according to the method of stimulus, *i.e.*, whether "unipolar"[1] or "bipolar," also requires very careful consideration. This is especially necessary since, although the unipolar[2] method offers at first sight special advantages in the exploration of deeply situated central mechanisms, it theoretically and actually conduces to errors of observation.

(*d*) *Bipolar excitation.*—When the bipolar method is employed with the electrodes 1 to 2 mm. apart the cortex cerebelli gives no response on the average until the 4,000 or even the 8,000 point on the Kronecker scale is reached. It was soon obvious to us in exploring by means of the unipolar method the posterior surface of the cerebellum, covered as it is by the strong arachnoid membrane forming the posterior and lower limit of the large cerebrospinal fluid *cisterna* opposite the lower third of the cerebellum and obex, that lateral escape of the stimulus to the margin of the fourth ventricle[3] and to the trunk of the spinal accessory nerve frequently occurs. Probably most previous descriptions of representation of trunk muscle movements in the cerebellar cortex based upon excitation experiments are to be accounted for by this accidental error.

This erroneous effect is composed primarily of movements of the upper shoulder group of muscles, so that its topography is obvious, while the character of the response is so sharp that it definitely displays itself as the effect of a peripheral nerve excitation rather than that of nerve centres such as in the cortex cerebelli.

We have made a series of experiments to compare in this respect of causing local error the unipolar and bipolar methods of excitation respectively. The results are not only striking as showing what very special care must be used in employing the "unipolar" method for localization experiments, but the subject is also of such vital importance to the present investigation that we devoted much time to investigating with the faradic current the whole question of the absolute and relative excitability of the cerebellar cortex.

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[1] *Cf.* Sherrington [22].

[2] The expression unipolar frequently applied to faradic current is really scarcely accurate although perhaps convenient. We have therefore made special investigation of the use of one electrode, and the full discussion of the question is given subsequently. (*See* pp. 119-121.)

[3] *I.e.*, region of nucleus gracilis, nucleus cuneatus, the tubercle of Rolando, &c.

In the first place we established as standards the excitability of the frontal and occipital cortico-cerebral areas for the movement of conjugate deviation of the eyes, and as an example of the comparisons obtained here subjoin the results of a typical experiment, which shows the minimal stimulus required to evoke the movement of *conjugate deviation of the eyes*, from the different chief points in the encephalon in which that movement is represented.

	CEREBRUM.				CEREBELLUM.	
	1 *Inferior frontal gyrus* (Conjugate deviation of eyes centre.)	2 *Corona radiata cerebri beneath No. 1.*	3 *Occipital lobe, upper and outer surface.*	4 *Corona radiata cerebri beneath No. 3.*	5 *Left half of vermis pyramid.*	6 *Left nucleus fastigii region.*
Minimal stimulus in Kronecker coil-units of current	... 100 ...	30 ...	200 ...	50 ...	No effect at 2,000 ...	10

We next proceed to study the relative effects of unipolar and bipolar stimulation. To the bipolar method of faradic excitation, the electrode points being either 1 mm. or 2 mm. apart, we have found that the cortex cerebelli is unquestionably not excitable, *i.e.*, no muscle response followed the application of the electrodes even when the coil distance represented 4,000 units of the Kronecker scale, and in some cases even 8,000, *i.e.*, at a point when the tension of the current was sufficient to cause frequent sparking between the electrodes when separated 1 mm.

When the whole surface of the cerebellum was thus explored with a hypermaximal stimulus the trapezial group of muscles began to contract with gradually increasing force as the electrodes were gradually brought down towards the edge of the fourth ventricle, and lower still to the neighbourhood of the spinal accessory trunk.

The delimitation of the spinal nuclear representation of the trapezius and other cervico-scapular muscles has not to our knowledge been specifically determined.

We have therefore made a few observations on this point as follows:

(*a*) *Anatomy.*—The most oral root of the *spinal* accessory nerve takes superficial origin from the bulb in the :—

(1) Cat. In the zonular level of the angle of the posterior border of the external arcuate fibres.

(2) Dog. In the zonular level of the same point.

(3) Monkey (*Macacus rhesus*). In the zonular level of practically the same point, *i.e.*, about 1 mm. above the obex.

Thus the bulbo-spinal representation of the shoulder muscles must be regarded as extending headwards as far as the large celled vestibular nucleus and consequently all excitation of the posterior cervical roots, and of the columns and nuclei of the obex region, will theoretically respond by contraction of the muscles named.

(*b*) *Physiology.*—Risien Russell [18], by excitation of the anterior cervical roots, showed that the first cervical nerve supplied the trapezius with other muscles. We have obtained the same response on stimulation of the bulb: (1) Nucleus gracilis. (2) Nucleus cuneatus. (3) Tubercle of Rolando.

That these results are due both to direct excitation of the bulbar representation and escape to the accessory trunk itself is proved by the fact that excitation after section of the highest roots is followed by the trapezial group movement though weaker.

With unipolar excitation the errors due to escape of current appear much earlier than with the bipolar method, and we will now give further facts which show the misleading character of the response to unipolar excitation of the surface of the cerebellar cortex.

For unipolar excitation we employed as the localizing (or as Sherrington terms it the "stigmatic") electrode the glass-insulated needle before described, and for the other either the wide attachments of the brass head piece or a broad metal plate expansion, which was inserted beneath the skin of the back or applied to any other selected spot. We also tried as a diffusing electrode a large area of wet linen applied to the shaved surface of the skin of the lumbar region.

When the surface of the cerebellar cortex was explored with the single insulated needle point and one of the above-named "indifferent" electrodes, the first effect was observed when the Kronecker coil strength reached 1,600 units. The response that then followed was invariably contraction of the trapezius, usually of the same side, but with stronger currents, *e.g.*, 2,000, &c., it easily became bilateral.

The degree of this typical response always steadily increased as the exciting electrode point was brought down towards the nucleus cuneatus. The natural conclusion follows that the effect was an "escape" phenomenon, and therefore such unipolar responses cannot be accepted as evidence of function.

To test this further, and to get if possible some idea of the amount of the error produced by the conditions of application of the electrodes, we next tried several variations of the unipolar excitation method. In the first place we found that the muscle response was notably diminished by shifting the other (the so-called " indifferent ") electrode from the lumbar region of the spine to the frontal bone.

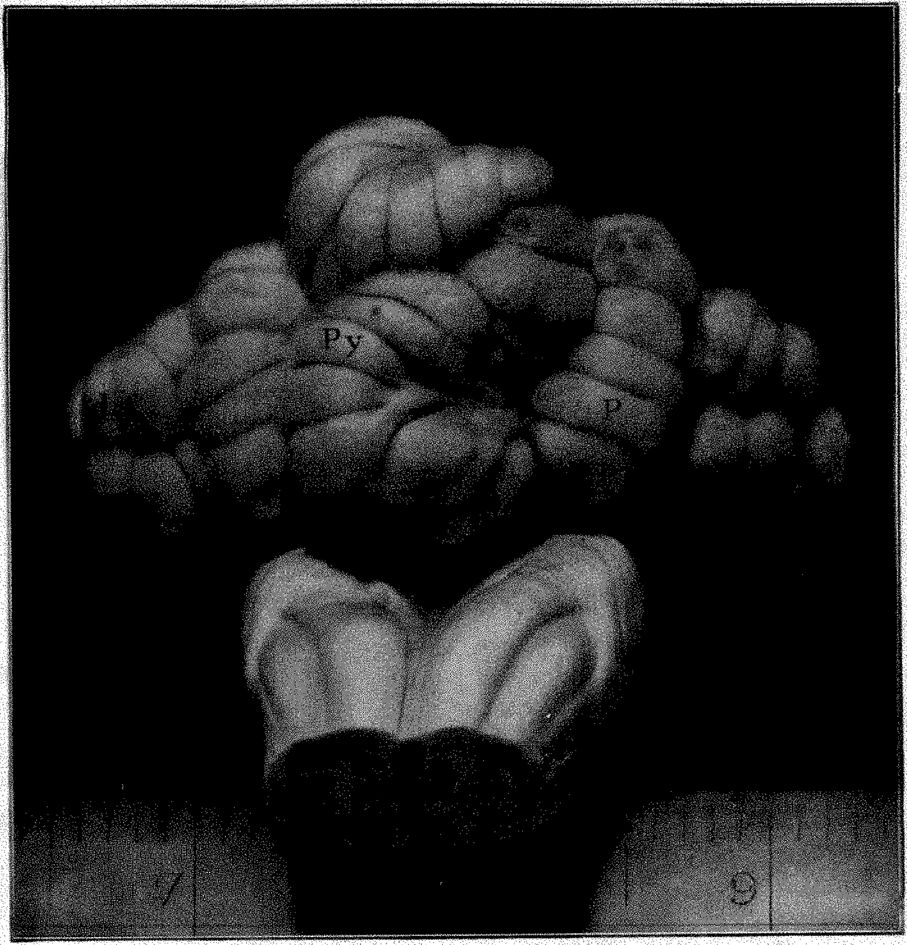

Fig. 30.

Normal cerebellum in the cat enlarged to show how the white fibres in the paramedian fissure (between Py and P) lie on the surface, and consequently exposed to any stimulus applied in the region of the sulcus.
df Dorsal paraflocculus.
Py Pyramidal lobe.
P Paramedian lobe.
The smaller divisions on the scale are millimetres.

In the second place when the unipolar electrode was placed on the surface of the pyramidal lobe of the cerebellum, and surrounded by either (1) a copper ring, or (2) the same ring covered with absorbent wool, or (3) a circle of amadou, the response was in each case very greatly diminished, *i.e.*, to about one-third of its former value.

An additional important (physiological) point is that even in all excitations of the free surface of the cortex with the marked escape to the trapezial group just described, we never, except when the localizing electrode was placed on or close to the paramedian sulcus, observed unequivocal concurrent movements of the eyes or conjugate turning of the head. The reason for the positive result occasionally obtained from the paramedian sulcus region must now be considered, and will be found to depend upon the anatomical conditions of the region which enable the stimulus to reach the subcortical structures most readily at this particular point.

The paramedian sulcus, which is so strongly marked in the carnivora and well developed in the macacque monkey, is a deep furrow filled only with loose pia mater. The cortex of the ends of the folia of the vermis, and to a similar degree of those of the paramedian lobe, ceases close to the surface of the organ; consequently the white fibres leading to the subjacent nuclei are, at this point, actually freely exposed within 2 mm. of the surface (*see* fig. 30).

Indeed in the dog and cat, where the pyramid constitutes the extreme sigmoidal flexure of the vermis, it can be seen with the operating lenses that the white fibres are often actually exposed on the free surface of the organ. In such a case obviously the response to excitation at that point would not be of cortical but nuclear origin.

The positive effects from excitation of the paramedian sulcus, which Nothnagel, Ferrier, and Hitzig have found comparatively easy to obtain, and which we also have seen, are therefore more correctly explicable as due to stimulation of the nuclei and not of the cortex.

A simple demonstration of the fallacious evidence yielded by unipolar excitation is given by first obtaining the usual false trapezial response with the unipolar electrode, and then immediately changing this for bipolar electrodes with the same coil; the result is immediate absence of any muscular contraction.

Our general conclusions from the whole of these facts are as follows

(1) The unipolar method of excitation is not accurate for investigation of the localization of function in the cerebellum.[1]

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[1] While this paragraph was being composed a second communication by Lourié [10] appeared, also proving that the unipolar excitation gave results which were wholly explicable as escape of current, and therefore that the above-stated conclusion is true.

(2) The bipolar method of excitation shows that the cortex cerebelli is not like a "motor" centre intrinsically excitable to the electric stimulus.

The cortex cerebelli is therefore in accord with Edinger's views to be considered wholly as a sensory organ which is in relation with certain lower, *i.e.*, basal centres, viz., the dentate, roof and emboliform nuclei these act as the motor equivalent to the sensory representation in the cortex.

We have shown before (*Brain*, 1905) that the anatomical architecture of the cerebellum exhibits no provision of direct efferent paths from the cortex except to the neighbouring nuclei, therefore our present conclusions regarding the functional activity of these two great divisions of the small brain are in full accord with the anatomical facts.

Relative Excitability of the Cortex Cerebelli compared with that of the Cortex Cerebri.

The question of the comparative excitability of the cerebellar and cerebral cortex respectively is interesting from the general physiological aspect, and although the two organs are commonly regarded as similar in design it seems to be forgotten that the structure of the cerebellar cortex is very specialized and not like that of any other nerve centres, *e.g.*, cerebral pallium, which have been similarly investigated.

Assuming the commonest movement represented in the cerebellum to be that of deviation of the eyes, it is worth while to compare the degree of response when the cerebrum and cerebellum are respectively excited. Reference back to the table on p. 118 shows that the response which was readily evoked from the cortex cerebri by a stimulus of 100 units is hardly to be obtained from the cerebellum until such a strong stimulus is applied that it obviously excites the nuclei of the cerebellum directly, and indeed all nuclei in the neighbourhood.

It will, of course, be conceded that while every sensori-motor centre must be excitable, notable differences of degree of excitability exist even between those in the cerebral cortex: *e.g.*, the visuo-sensory occipital cortex cerebri compared to that of the præcentral gyrus. It appears to us that a parallel though greater functional separation exists between the cortex cerebelli and the intrinsic nuclei. Consequently whatever be the kinds of movements represented in the cortex cerebelli in their preliminary sensory stage, it is not probable that they are localized in the manner generally understood as motor localization in the cerebrum.

There are, moreover, two more points which in our opinion add weight to the view we are now pressing, viz., that the cortex cerebelli ought not to be regarded physiologically as of the same class of nerve centre as the cortex cerebri.

These two points are (1) stimulation after-effects, (2) intra-vital methylene blue reduction, and must be considered separately.

(1) *Stimulation after-effects.*—Perhaps the most striking feature of difference between the functions of the cerebral and cerebellar mechanisms as a whole is that while the cerebral excito-motor cortex is so essentially productive of very gross after-effects (epilepsy), excitation of the cortex of the cerebellum is not followed by any such phenomena. It is the consideration of the absence of this mode of discharge of nerve energy that led us to a series of experiments with another vital test, viz., that of methylene blue by Ehrlich's method, since the experience of one of us (V. H.) of a large series of experiments in 1893 showed that the cerebral cortical discharge (as originally discovered by Ehrlich) caused an active reduction of the blue in proportion to the degree of development of the epileptic after-effect.

(2) *Comparison of the cerebral and cerebellar intra-vital blue reaction.*—Before stating the contrast between the two organs which we have found, it is necessary to point out that, as shown by one of us and by Eve, there is a slight but distinguishable reduction of methylene blue by a strong (*i.e.*, hypermaximal for excitation of the cortex) faradic current between electrodes 2 mm. apart. But in this method of investigating the cerebral cortex the most striking feature of the activity of the nerve centre is that apart from any slight change due to the current itself the blue colour only materially fades out when the epileptic discharge commences, and then the nerve centre, the seat of the excitation, is left pale white. The method thus offers a valuable means of physiological comparison between the cerebral and cerebellar cortex respectively.

In our experiments specially on this point we have investigated the excitation of these two parts of the encephalon in dogs and cats. The total quantity of 5 per cent. solution of methylene blue injected intravitally has been on the average 400 c.c. to 500 c.c. when employed subcutaneously, or about 60 c.c. when infused into a vein direct.

Stimulation of the cortex cerebelli produced either no change in its blue tint or a slight and doubtful one, and offered a strong contrast to the clear paling on exciting the "motor" region of the cortex cerebri. It follows, therefore, that according to this evidence there is no maximal outflow of energy from the cerebellar cortex comparable to that of the cerebral "motor" cortex.

(3) *Relative excitability of the cortex cerebelli compared to that of the nuclei cerebelli and efferent tracts therefrom.*—Perhaps the most concrete result of our method of investigating the cerebellum is the revelation of the motor functions of the intrinsic cerebellar nuclei as demonstrated by excitation. As already stated the negative result of bipolar excitation of the cortex cerebelli gradually changes into a positive effect as the needle passes forwards among the axones of the Purkinje cells running to the nearest nucleus until the stimulus is directly applied to the nucleus itself, or to the paths and tracts issuing from it when the result becomes maximal with even a very weak excitation.

The full detail of the representations of function which this method has revealed in the cerebellar nuclei we will give in Part II. of this communication.

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Dedicated to Professor Edinger on the occasion of the opening of his new Laboratory.

ON THE CONNECTION OF THE INFERIOR OLIVES WITH THE CEREBELLUM IN MAN.

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ALTHOUGH it is well known that atrophic changes may occur in an inferior olive secondary to lesions of the contralateral half of the cerebellum there are, as far as we know, no direct observations on the regional relations of these two parts.

The investigations of Lewandowsky [7], van Gehuchten [2] and others by the Marchi method have made it practically certain that the fibres which connect the inferior olives with the cerebellum are entirely cerebellopetal; this has been confirmed by the exact observations of Yagita [12], who has recently shown that in the rabbit practically all the cells of the one olive undergo reactionary chromatolysis when the opposite corpus restiforme has been cut across, while in the olive of the same side as the lesion changes are found in a small proportion of the cells only. From these facts, therefore, the conclusion may be drawn that the fibres which connect the inferior olives with the cerebellum are entirely olivofugal, and that the atrophy of the olivary cells which was first described by Meynert, and has since then been frequently observed after both experimental and pathological lesions of the cerebellum, is directly due to destruction of these fibres.

The portion of the cerebellum in which these olivo-cerebellar fibres terminate has not been, however, definitely determined; this is evident from the following short review of the more important of the papers which have recently dealt with the subject.

According to Thomas [11] these olivo-cerebellar fibres terminate only in the cortex of the cerebellum, and have no direct connection with the dentate or its other nuclei. In the cat he found that the majority of them end in the vermis, some after decussation in the middle line. He thinks it probable that in man, owing to the greater development of both the inferior olives and the lateral lobes of the cerebellum, these two parts may be directly connected.

According to Klimoff [5], on the other hand, the olivo-cerebellar fibres which enter the cerebellum through the one corpus restiforme terminate in both the vermis and the lateral lobes, and chiefly on the same side.

Keller [4] traced the olivo-cerebellar fibres in the cat only to the posterior portion of the superior vermis. Some of them he saw decussating in the cerebellum. The roof nuclei may receive collaterals, but few, if any, fibres end in the dentate nuclei. He was unable to trace any fibres into the lateral lobes of the cerebellum.

Probst [8] also produced experimental lesions in the neighbourhood of the inferior olives. He found that the only cerebellopetal fibres which degenerated terminated in the anterior and the posterior portions of the superior vermis.

Lewandowsky [7], despite the large amount of experimental material which he possessed, could only come to the conclusion that the olivo-cerebellar fibres end chiefly in the lateral lobes and flocculus; he could not determine with certainty whether any entered the vermis, as degeneration of these fibres was always associated with degeneration of the spino-cerebellar tracts which end in the vermis.

Van Gehuchten [2], although convinced that the connection of the inferior olives with the cerebellum is entirely olivofugal, was not able to ascertain definitely where the olivo-cerebellar fibres terminate in the cerebellum, as when he obtained degeneration of these fibres by lesions in the neighbourhood of the olives other cerebellopetal fibres were also injured.

Several years ago Risien Russell [9] came to the conclusion that the olivo-cerebellar fibres terminate not in the cerebellar cortex but in the dentate nuclei, as in the cerebellum of a puppy which he examined the pathological changes were limited to the cerebellar cortex and the inferior olives were intact. As, however, the cortical abnormality was due to a developmental anomaly and not to a degenerative process this conclusion was scarcely justifiable. Babinski and Nageotte [1] have recently come to the same conclusion. They examined a case in which there were several foci of softening in the medulla, due to syphilitic vascular disease, and observed degenerated fibres which ascend to the cerebellum through the corpus restiforme, bend over the dentate nucleus and end in this and in the embolus, while none could be followed into the cerebellar cortex. Laignel-Lavastine [6] also supports this view; he examined a case in which there was an old focus of softening in the white matter of one lateral lobe of the cerebellum and found atrophic changes in the contralateral olive, but as the primary lesion involved the corpus restiforme in the cerebellum it is difficult to see how he came to this conclusion. The conclusions of the French authors can be of little weight when compared with the results obtained by more exact experimental lesions. In the case described by Babinski and Nageotte the interruption of the fibres involved in the lesions was evidently very incomplete, while Laignel-Lavastine's conclusions were arrived at by the examination of material by Marchi's method two years after the occurrence of the primary lesion, when a large proportion of the degeneration products which are revealed by this method must have been removed.

The discrepancies between the conclusions of these different authors are evidently due to the fact that the olivo-cerebellar fibres can be traced only by the degeneration methods, and as it is practically impossible to produce an isolated lesion of them, either at their origin or in their course, when degenerated they are practically always intermixed with degenerated fibres of other cerebellopetal bundles, and especially with those of the spino-cerebellar tracts.

Our investigations have been limited to the examination of the olives in cases in which there had been destructive lesions of various portions of the cortex of the cerebellum. We have been able to utilize for this purpose the central nervous systems of all the cases with local lesions in the cerebellum which have died in the National Hospital during the past five years.

As early as seven days after the occurrence of an acute and complete destructive lesion of the cerebellar cortex chromatolytic changes may be observed in the cells of the olive on the opposite side to the lesion; the marked swelling of the cells, with disintegration of the tigroid and eccentricity of their nuclei, is very prominent even within this period, and generally persists for some weeks. Some of these swollen cells may become vacuolated, and within three or four weeks after destruction of the olivo-cerebellar fibres many of the affected cells begin to atrophy and eventually disappear. After about six or seven weeks, in our experience, the majority of the cells of origin of the olivo-cerebellar fibres which have been destroyed by an acute lesion have disappeared, and in their place a secondary proliferation of the neuroglia, and eventually sclerosis and shrinkage of the olive occur. In cases in which the cerebellar lesions had been of long standing some diminution and atrophy of the olivo-cerebellar fibres could be demonstrated, especially of those within the contralateral olive.

We have found that those cases in which the cerebellar lesion was acute, and in which there was complete destruction of at least some portion of the cortex, were the most suitable for our purpose. Very little or no reactionary change could be found in the cells of the olives when even the greater portion of the contralateral half of the cerebellum had been infiltrated or slowly destroyed by a tumour. This observation is analogous to the fact that the ventral horn cells of the cord may remain structurally intact when a peripheral nerve is injured by slow compression, while they undergo marked chromatolysis if the nerve is suddenly cut across, and especially if it is roughly torn out. In the greater number of the specimens we have made use of, some portion of the cerebellum had been completely destroyed, either in the removal of a tumour or by surgical exploration some time before death. In one of the cases, however, there was only a primary degeneration of the cerebellar cortex, and in another a small area of cortex had been destroyed by a carcinomatous tumour growing from the pia mater. When, however, cerebellar lesions of slow and gradual evolution had persisted for a long period before death, atrophy and disappearance of some of the cells of the opposite olive could be sometimes observed. In a few of our cases, for instance, in which part of the cerebellum had been destroyed by a slowly growing tumour and another part damaged by operative procedures a short time before death, we found some of the olivary cells undergoing these slow regressive changes and others in the state of acute *réaction à distance.*

From the examination of the material at our disposal we have come to the conclusion that definite portions of each olive are connected with definite portions only of the cortex of the lateral lobes and of the vermis of the cerebellum. With regard to the flocculus we are unable to say anything, as this portion of the cerebellum was not injured in any of the focal lesions we have observed.

Case 1.—In October, 1905, an exploratory operation was performed over the left lateral lobe of the cerebellum; the dura mater was opened, but the cerebellum was not incised. The patient died seven months later. *Post-mortem* examination revealed a sarcoma of the base of the skull. It was found that the lateral margins of the postero-superior, postero-inferior and gracilis lobes of the left side of the cerebellum were completely destroyed; the rest of the cortex was intact. The softening did not extend deeply into the white matter, and only touched the postero-lateral angle of the dentate nucleus.

Olives.—The changes were limited to the extreme lateral portion of the right inferior olive. In this region at all levels there was a marked reduction in the number of the cells; some of those which remained were in the state of chromatolysis; others were very much atrophied. A few swollen cells were seen in the corresponding region of the left inferior olive. The accessory olives were intact (fig. 1).

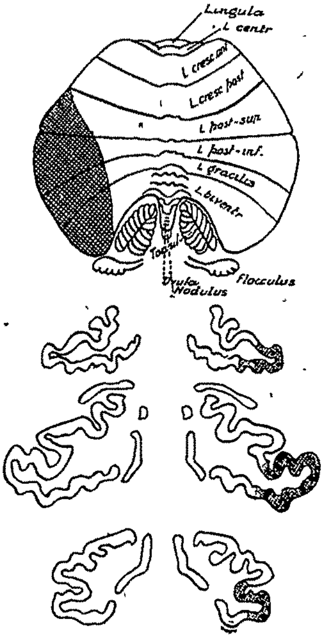

FIG. 1.

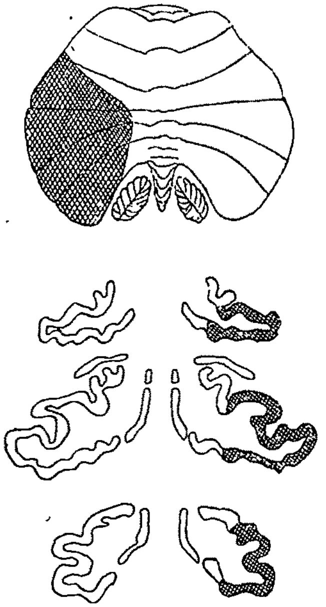

FIG. 2.

The diagrams show the area of the cerebellar cortex which was destroyed in each case, and the region of the contralateral olive in which changes were present. Fig. 1 represents Cases 1 and 2; fig. 2, Cases 3 and 4.

In each diagram three different levels of the inferior olive are drawn, from above downwards, the frontal third, the middle, and the caudal third.

The slighter changes in the homolateral olives are not indicated in these diagrams.

Case 2.—In May, 1904, a tubercular tumour was removed from the lateral portion of the left lobe of the cerebellum. Seven weeks later the patient died from tubercular meningitis. It was found that the lateral portions of the postero-superior, postero-inferior, gracilis and biventral lobules had been destroyed. The rest of the cerebellum was intact. The operative lesion did not extend down to the neighbourhood of the dentate nucleus.

Olives.—No normal cells could be seen in the lateral portion of the right inferior olive; the majority had disappeared, others were extremely atrophied and a few were chromatolytic. The extent of the affected area was approximately the same as in Case 1, but it extended somewhat further medialwards along the ventral fold.

Case 3.—A large gumma was removed from the left lateral lobe of the cerebellum in October, 1904. The patient died about two years later from renal disease. On *post-mortem* examination it was found that there was no active cerebral disease, but the greater part of the left lateral lobe of the cerebellum was absent; the only portions which remained were the anterior and posterior crescentic lobules, the medial portion of the biventral, and the tonsil and flocculus. These parts were uninjured. A considerable portion of the central white matter had been removed, and the lateral part of the dentate nucleus had been damaged. The vermis and the right lobe were intact.

Olives.—There was an almost complete absence of cells in the lateral two-thirds of the right inferior olive. The region affected was considerably greater than in Cases 1 and 2; it extended further medialwards in both the dorsal and ventral folds of the olive, but especially in the former. The rest of the inferior olive, as well as the accessory olives, were intact (fig. 2).

Case 4.—Nine days before death the left lateral lobe of the cerebellum was explored and cut into. At the *post-mortem* examination a large tumour was found in the right frontal lobe. The greater portions of the postero-inferior, gracilis and biventral lobes, as well as the lateral extremity of the postero-superior lobe, had been destroyed. The rest of the cortex was intact, but the operative incision extended down to the dorso-lateral part of the dentate nucleus.

Olives.—Practically all the cells of the lateral half of the right inferior olive were in the state of acute reactionary chromatolysis. The area in which the affected cells were found was almost identical with the area of change in Case 3. A few cells showing *réaction à distance* were present in the same region of the left inferior olive.

In these four cases in which the lesion of the cerebellum was limited to the lateral portion of one lateral lobe we found changes in the lateral portion only of the contralateral olive. We may therefore conclude that the olivo-cerebellar fibres which terminate in the cortex of the lateral folia of the cerebellum arise from the cells of the lateral portion of the opposite inferior olive. In Cases 1 and 2, in which the lateral extremity only of the cerebellum was involved, the olivary change was considerably less extensive than in Cases 3 and 4, in which a much larger area of the cerebellar cortex had been destroyed. From this we may further conclude that the cerebellopetal fibres which spring from the lateral extremity of the one olive end in the cortex of the most lateral portions of the opposite side of the cerebellum, while those which arise from the adjoining portions of the dorsal and ventral folds of the olive terminate in the middle zone of the lateral lobe of the cerebellum.

Case 5.—At the *post-mortem* examination a small carcinomatous tumour was found in the middle of the left postero-inferior lobule. It had entirely destroyed the cortex of this lobe and the neighbouring margins of the postero-superior and gracilis, but it extended only a very short distance into the white matter.

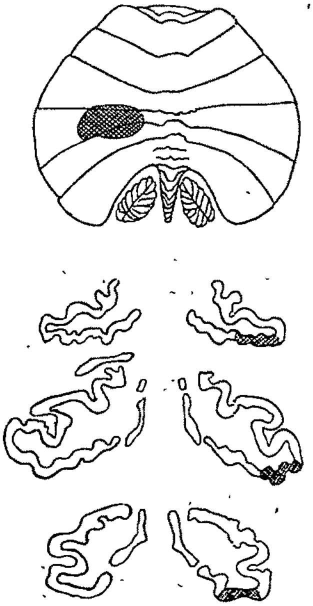

FIG. 3.

Olives.—Cells in chromatolysis were found only in the lateral end of the ventral fold of the right inferior olive. They did not extend quite to the lateral extremity of the olive (fig. 3).

Case 6.—The patient died seven days after an operation on the right lateral lobe of the cerebellum for tumour. The cerebellum was not incised, but at the autopsy it was found that a portion of its cortex had extruded through the opening in the dura mater and had been destroyed. The portion destroyed belonged to the posterior margin of the lateral half of the postero-superior, the lateral three-quarters of the postero-inferior, and the central portion of the gracilis. The lesion was quite superficial. The tumour lay in the centre of the left lateral lobe; it compressed but did not destroy the left dentate nucleus.

Olives.—All the cells of the lateral extremity of the left inferior olive and of the lateral portion of its dorsal fold were in the state of acute chromatolysis. The rest of the inferior olive and the accessory olives were unaffected.

In Cases 5 and 6 the area of cerebellar cortex destroyed was much less extensive than in the four previous cases, and corresponding thereto the region of the olives in which changes could be observed was much smaller. In Case 5, in which the extreme lateral portion of the cerebellum escaped, the changes observed in the contralateral olive did not extend to its lateral tip; on the other hand, in Case 6, in which the most lateral folia were destroyed, the majority of the cells of the lateral extremity of the contralateral olive were in chromatolysis. These cases therefore confirm our previous conclusions.

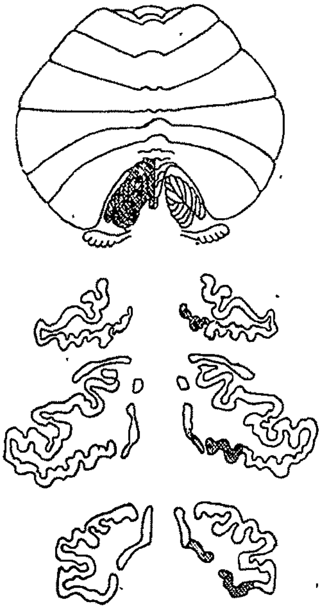

FIG. 4.

Further, in Case 5, the lesion was practically limited to the inferior surface of the cerebellum, and the cell changes were limited to the ventral fold of the opposite olive. This indicates that the ventral fold of the olive is in connection chiefly with the inferior surface of the cerebellum.

Case 7.—This was a case of primary degeneration of the cerebellar cortex which has been already described by one of us [3]. The only portion of the cortex which escaped was that of the tonsils, the uvula and the nodule. The cerebellar nuclei were unaffected.

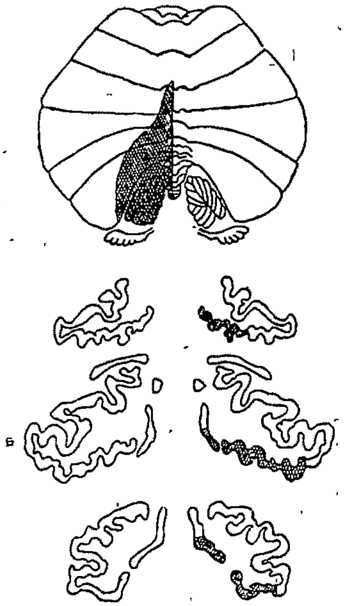

FIG. 5.

Olives.—The only portion of the inferior olives in which any cells remained were the medial ends of the ventral folds and the ventral extremities of the medial accessory olives. In the rest not a single cell could be seen, and the tissue was densely sclerosed (fig. 4; the normal parts of both the cerebellum and the olives are cross-hatched).

Case 8.—This patient had been repeatedly operated on for a cerebellar gliomatous cyst of long duration. On *post-mortem* examination of the cerebellum it was found that the inferior vermis and the declivum, as well as the tonsil and the adjacent parts of the biventral and gracilis lobes of the left side, had been destroyed.

Olives.—The majority of the cells of the ventral fold of the right inferior olive and of the ventral extremity of the medial accessory olive, had disappeared, and those which remained were atrophied and shrunken. The lateral portion of the inferior olive escaped, and the dorsal fold and the dorsal accessory olive were intact (fig. 5).

Case 9.—The patient died sixteen days after a portion of a tumour had been removed from the right lateral lobe of the cerebellum. The medial two-thirds of the postero-inferior and gracilis lobes, the greater portion of the biventral, and the medial folia of the postero-superior lobe were destroyed by the operation; the tumour had destroyed the pyramid, the tuber valvulæ and the declivum.

Olives.—There were two varieties of cell change in the olives. In the first place acute tigrolysis of practically all the cells of the ventral fold of the left inferior olive, except in its medial end; a smaller number of cells were also seen in chromatolysis in the corresponding area of the opposite olive. In the second place there was a definite numerical diminution of cells in the left medial accessory olive, and the majority of those which remained were atrophied.

In Case 7 the only portion of the cerebellar cortex which was normal was that of the nodule, uvula and tonsil; normal cells were present only in the medial portion of the ventral fold of the inferior olive and in the ventral portion of the accessory olive. We may, then, conclude that the olivo-cerebellar fibres which spring from this part of the olive terminate in that region of the cerebellum. This observation is apparently supported by the findings in a somewhat similar case reported by Schweiger [10], in which the tonsil was almost normal and the vermis was very much less affected than the cortex of the lateral lobes. According to his description the medial accessory olives were relatively intact, and from one of his illustrations at least (fig. 4) it is evident that the medial portion of the ventral fold of the inferior olive was but little affected. Case 8 also confirms this conclusion, but as the mesial portions of the gracilis and biventral lobes had been also destroyed, the area of change in the inferior olive extended further lateralwards in its ventral fold.

In Case 9 the superior segments of the inferior vermis were destroyed by a tumour, and the cells of the dorsal part of the medial accessory olive were atrophied; possibly these two regions are connected. In Schweiger's case, which has been already referred to, the whole of the vermis was relatively intact and the dorsal part of the medial accessory olive was one of the only portions which escaped secondary atrophy. In Case 8, however, the dorsal segments of the inferior vermis were also invaded by tumour, yet no changes were observed in that portion of the medial accessory olive; this may have been due to the nature of the cerebellar lesion.

Case 10.—In 1904 a cerebellar cyst was opened through the middle of the left postero-inferior lobule. The patient made a complete recovery and remained free from symptoms for three and a half years. Owing to the recurrence of symptoms she was again operated upon in the same region, and a large gliomatous cyst was removed. She died seven weeks later. The greater part of postero-superior, postero-inferior and gracilis lobules of the left half of the cerebellum were destroyed by the last operation, and the biventral was seriously bruised. The tonsil had shrunk to one-third of its normal size, but the flocculus was intact. On the right side practically the whole of the postero-superior, postero-inferior, gracilis and biventral lobules were destroyed by a large cyst, which had also destroyed the whole of the inferior vermis.

Olives.—It was difficult to interpret the olivary affections in this case as there were at least three cerebellar lesions of different nature, duration and distribution. We observed: (1) reduction in number of cells in the lateral portion of the right olive, corresponding probably to the first operation wound; (2) a slight loss of cells and marked tigrolysis of the rest in the ventral fold of this olive, due probably to the later operative incision and the removal of a tumour from the inferior surface of the left lateral lobe; (3) atrophic changes in the whole of the ventral fold and in the lateral half of the dorsal fold of the left inferior and the medial accessory olive, secondary probably to the destruction of the right side of the cerebellum by the cyst. The chief value of this case is that the only part of the cerebellum which was uninjured was the frontal portion of its superior surface, while normal cells were found only in the dorsal accessory olives and in the medial halves of the dorsal folds of the inferior olives.

The superior vermis, the central, and the two crescentic lobules of the cerebellum escaped injury in all the focal lesions we have observed; in Case 10 these were practically the only portions of the cerebellum which were intact; the mesial halves of the dorsal folds of the inferior olives and the dorsal accessory olives were also unaffected in all these cases. In Case 7, on the other hand, the cortex of the whole of the superior surface of the cerebellum was degenerated, and these portions of the olives contained no cells. The conclusion, therefore, appears justified that the olivo-cerebellar fibres which arise from the dorsal accessory olive and the medial half of the dorsal fold of the inferior olive terminate in the superior vermis and the superior surface of the cerebellum.

We recognize that our conclusions from these observations cannot be final, as the lesion was not in every case limited to the cortex of the cerebellum, and some of the olivo-cerebellar fibres destined for undamaged portions of the cortex may have been injured in their course through the subcortical white matter. But we could exclude this in a certain number of our cases. It appears to us certain, however, that there is a definite regional relationship between the different portions of the cortex of the cerebellum and the various parts of the inferior and accessory olives. We cannot, with certainty, say that the olivo-cerebellar fibres terminate in the cortex of both the lateral lobes and of the vermis, as we have no cases in which the vermis alone was damaged or in which the lesion was limited to, but included the whole of, the lateral lobes. It appears to us probable that it is so.

In one of our cases the primary disease was limited to the cortex of the cerebellum (Case 7), and in others the lesion involved only the immediately subcortical white matter. In these cases practically all the cells of some one or other portion of the olives had undergone definite changes. We can therefore conclude that all the fibres which the olives send to the cerebellum terminate in the cortex and not in the central nuclei. Further, as we have found complete absence of cells in all portions of the olives in one or other of our cases we may draw the conclusion that all the fibres that take origin from the cells of the olives terminate in the cortex of the cerebellum.

The connection of each olive is chiefly with the contra-lateral side of the cerebellum, but in all our cases in which the lesion was recent and had produced chromatolysis of the olivary cells this change could be detected in a small proportion of the cells in the corresponding portion of the olive homolateral to the cerebellar lesion. This fact has been already ascertained by Yagita and others in experiments on animals.

CONCLUSIONS.

(1) All the cells of the inferior and the accessory olives send their axis cylinders to the cerebellum.

(2) The connection of each olive is chiefly with the contralateral half of the cerebellum.

(3) The olivo-cerebellar fibres terminate in the cortex of the lateral lobes, and probably also in the vermis of the cerebellum. Certainly no large proportion of them end in the cerebellar nuclei.

(4) There is a definite regional relationship between the different portions of the inferior and accessory olives and the different areas of the cortex of the cerebellum (fig. 6) : (*a*) the lateral portions of the

olives are connected with the lateral portions of the opposite side of the cerebellum; (*b*) the medial ends of the inferior olives and the medial accessory olives send fibres probably to the vermis and the mesial portions of the lateral lobes of the cerebellum; (*c*) the dorsal fold of the olive is in connection chiefly with the superior surface of the cerebellum; (*d*) the ventral fold of the olive sends the fibres chiefly to the inferior of the cerebellum.

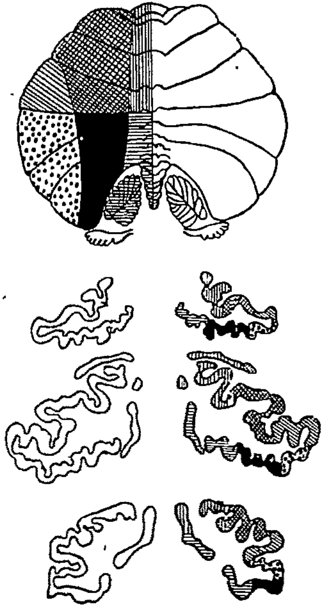

FIG. 6.

A composite diagram to illustrate the Conclusions. The regions of the cerebeller cortex and the inferior olives which correspond are indicated by similar markings.

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THE EFFECT OF STRUCTURAL CHANGES CONNECTED WITH THE DEVELOPMENT OF BINOCULAR VISION ON ASSOCIATED MOVEMENTS OF THE EYES.

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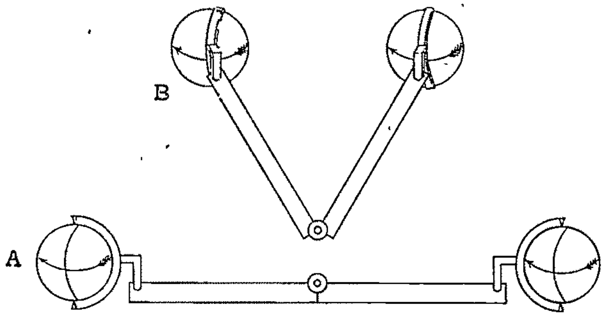
IN the evolution of binocular vision from the divergent eyes of primitive vertebrates a considerable change takes place in the anatomical position of the eyes in the skull, and, as a matter of simple mechanics, this change of position must have a marked effect on those associated or conjugate rotations of the eyes which had become habitual. In the primitive vertebrate the eyes look in opposite directions in the same axis at right angles to the spine; this is approximately the condition in many mammals—the armadillo is a good example—and the majority of birds, reptiles, and fishes. If we compare an animal of this class with a typical example of those which possess binocular vision, like the monkey or owl, the change in the position of the eyes in the latter is very marked, and it is evident that the difference in position may considerably modify the mutual relations of the rotations of the eyes on their own axes, and that a movement which is a conjugate rotation in one position may become a reverse rotation in the other. It will be seen presently that conjugate rotation in divergent eyes in the frontal and sagittal planes becomes reverse rotation in the position of parallel vision, while conjugate rotation in the horizontal plane remains conjugate in both positions. In the course of its evolution, therefore, the binocular animal was confronted with the alternative of continuing the old conjugate rotations of its eyes, with the result that two-thirds of these movements would be no longer conjugate but reverse, or of discarding the old habits and substituting new combinations. In applying the word selection to such cases as this, the idea of choice which it suggests is not wholly figurative. The supersession of an old habit by a new one must, for a time, involve the exercise of purposive direction, and how long such direction is required before the new movements become perfectly automatic; what is the relative status of centres which initiate a new combination and those which suffice for an old-established automatism; how long does a tendency persist to revert to the old habit when the directing influence is withdrawn; and does any such tendency still exists in binocular animals. These are questions which naturally suggest themselves, and a still more interesting one is, How did the new habits, when acquired, become hereditary? For as it is anathema to admit the possibility of acquired characters being transmitted, the only alternative seems to be that as soon as phylogenetic structural changes made it desirable that the simultaneous contraction of both superior recti should be substituted for the old association of one superior with the other inferior rectus, the advantage of this little change became so prodigious and assertive that not a single individual was permitted to live unless his germ-plasm enshrined the potential of the new combination and excluded the old; all the rest were exterminated by the agencies which eliminate the unfit—and no men or monkeys can now look up with one eye and down with the other at the same time, as their ancestors and ours always used to. We are accustomed to regard evolutionary changes as very gradual, perhaps imperceptible, but it does not appear that this one can have been so; originally one superior rectus always acted with the inferior rectus of the other eye; when it gave this up it went into partnership with the other superior rectus in simultaneous rotations of the eyes in the sagittal plane—it must have acted with one or the other; no transitional stage appears to be possible.

The effect of changes of position of the eyes on their associated movements is a question of simple mechanics which has not received much attention as far as I know, and it is worth further consideration on its own account, and still more because it is involved in various questions of interest to biology and physiology. I propose, therefore, to examine this point more closely. It will be sufficient in discussing variations of rotation to confine ourselves to three planes, horizontal, frontal and sagittal, the application of the same principles to intermediate planes being obvious. As frequent reference may be necessary to planes, axes, &c., which are relative terms, to avoid any ambiguity and for purposes of reference, if required, it will be advisable to agree on definitions of these and a few other terms in advance. As the normal visual axes of vertebrates are generally directed to the horizon, parallel to the apparent surface of the earth, the direction of these axes in two dimensions will serve to define the horizontal plane. The frontal plane is perpendicular to the horizontal and bisects both eyeballs, and the sagittal plane is perpendicular to both the others and bisects the skull—the definition must be extended to planes parallel to those described. The axes perpendicular to these planes will be referred to as vertical, longitudinal and transverse respectively. Conjugate rotation of two spheres or discs may be defined as simultaneous rotation in the same direction, in the same or parallel planes on the same or parallel axes. The wheels of a moving dog-cart serve as an illustration of conjugate rotation in the same direction in parallel planes on the same axis, and those of a bicycle in the same plane on parallel axes. The plane of rotation of a sphere is perpendicular to its axis. In a rotating disc or sphere a point on its periphery, regarded from its axis of rotation, moves to the right or left; that is the direction of its rotation.

The two varieties of movement of the eyes whose mutual reactions we have to examine may be compared to the double movement of the earth rotating on its axis and moving in an orbit round the sun. The eyes may rotate on their own axes in all planes, and in passing from the position seen in the armadillo to that in the monkey they may be described as traversing part of an orbit of which the centre is the chiasma and the radius the optic nerve. In binocular mammals and birds this orbit is in the horizontal plane, as in both the old and new positions of the eyes the normal visual axes are directed to the horizon. In these animals the change of position may be described as a forward movement of both eyes in opposite directions, so as to approach one another through corresponding segments of the same horizontal orbit, the centre of which is the chiasma and the radii the optic nerves; originally the optic nerves were in nearly the same straight line, but are finally brought to a V-shaped angle of about 60°, complete parallelism of the visual axes being obtained by slight inward rotation of the eyes on vertical axes. It is interesting to compare this method of passing from divergent to parallel vision with that which occurs in flat-fish like the plaice and flounder; here, instead of both eyes traversing equal segments of a horizontal orbit, one eye moves through nearly half a circle in the frontal plane towards the other eye, which is stationary. The decussation is still the centre and the optic nerve the radius of the orbit; but the most remarkable thing is that the change takes place in the life of the individual; the immature fish have divergent eyes, and as they develop the change of position referred to occurs. In the higher vertebrates the attainment of binocular vision is apparently the only object of the evolution, but in fish it seems to be merely a part of more general structural changes which render it necessary.

In the higher vertebrates the change from divergent to parallel vision is a phylogenetic evolution which has probably taken ages to complete; it is effected by moving both eyes forward through corresponding segments rather less than quadrants of the same horizontal orbit. In fish the process is ontogenetic and effected by moving one eye through nearly half a circle in a frontal orbit, which has the same centre and radius in both cases. Divergent eyes could only approach one another in the frontal or horizontal planes, and in the above we have instances of their doing so in both. We have now to consider the effect of these movements on the rotation of the eyes on their own axes, and it will facilitate description if we begin by examining the principle in a model representing both forms of movement before we apply it to animals. Like many other movements, they can be seen at a glance in a model, less easily in a diagram, while verbal descriptions are tedious and unintelligible. It is necessary to give descriptions in words, if only for reference, but I hope the diagram, rough as it is, may save some at least of the trouble of reading. The model (*see* fig. 1) consists of two globes arranged to revolve freely on axes or spindles pivoted at opposite ends of a bar hinged at its centre; the gimbals can be adjusted to allow the globes to rotate on their own axes in any plane, and, at the same time, they can be moved in an orbit, of which the hinge in the centre

Diagram of model which shows how a change in the position of the eyes affects their associated rotation. The model consists of two globes pivoted on gimbals permitting their rotation in any selected plane and fixed to the ends of a bar jointed at its centre. In the figures these parts represent the eyes, optic nerves, and the chiasma—(A) in divergent and (B) in parallel vision. The globes can be made to revolve in conjugation in the first position (A), and, while rotating, brought to the second position (B).



B Parallel vision.
Monkey.

A Divergent vision.
Primitive vertebrate—
armadillo, &c.

FIG. 1.

First position (A) represents conjugate rotation in the same direction in the same horizontal plane on parallel vertical axes.

Second position (B). Remains conjugate rotation in all positions in the same horizontal plane, the segment of the orbit traversed being in the same plane as the rotation of the globes on their own axes.

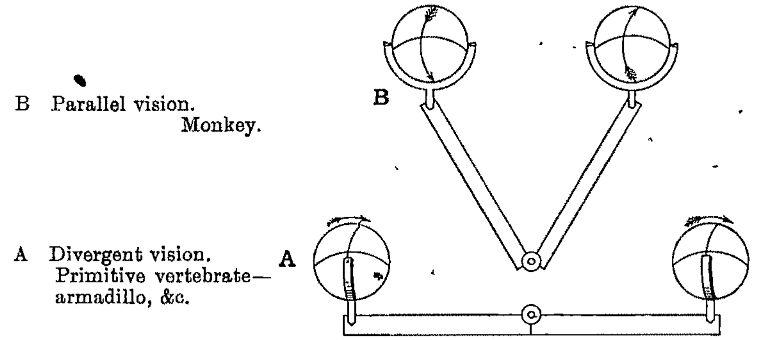


FIG. 2.

First position (A). Conjugate rotation in the same direction in the same frontal plane on parallel longitudinal axes becomes,

In second position (B), reverse rotation, in opposite directions, in parallel sagittal planes on the same transverse axis. The plane of rotation in this case is perpendicular to that of the orbit.

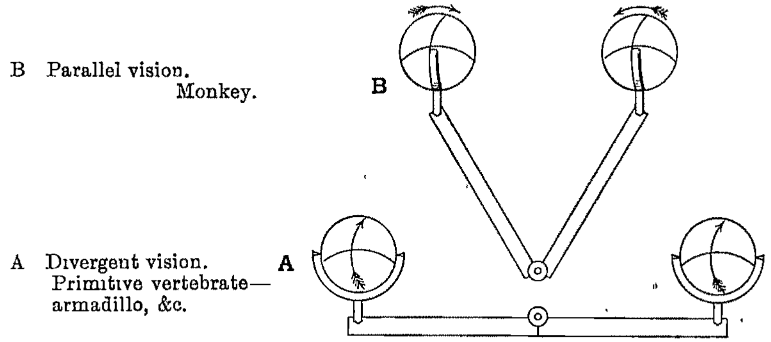


FIG. 3.

First position (A). Conjugate rotation in the same direction in parallel sagittal planes on the same transverse axis becomes,

In second position (B), reverse rotation, in opposite directions, in the same frontal plane on parallel longitudinal axes, the plane of rotation being perpendicular to that of the orbit.

represents the chiasma and the rod on either side of the hinge the optic nerves. The globes can be made to revolve in conjugate rotation, and while spinning can be moved into the positions of divergent or parallel vision. In the model it is apparent at once that if the globes are in conjugate rotation in the divergent position and they are moved to the parallel position through part of an orbit in the same plane as their own rotation, their rotation remains conjugate, *i.e.*, if they are in the position of divergent vision and rotating in the same direction in the same horizontal plane on parallel vertical axes and are moved (fig. 1), while revolving through corresponding segments of the same horizontal orbit, to the second position (parallel vision) their rotation will still be conjugate, and it will be so in any position in that horizontal orbit. But if the plane of rotation on their own axes is perpendicular to the orbit, then the plane and axis of their own rotation change with each quadrant of the orbit they traverse (fig. 2 A). Thus if the globes are in conjugate rotation in the first position, in the same frontal plane, in the same direction and on parallel longitudinal axes, if each of them is moved forwards through one quadrant of a horizontal orbit so as to come together in front, they will be revolving in reverse directions in parallel sagittal planes on the same transverse axis (fig. 2 B). Conjugate rotation in the first position becomes reverse rotation in the second. The plane and axis of rotation have been changed in each globe after moving through one quadrant of the horizontal orbit. If both globes could be moved on through another quadrant they would be again rotating in the frontal plane on longitudinal axes as at first, and so with each quadrant of the horizontal orbit through which they are moved.

It can be seen equally easily that if the globes in the first position are in conjugate rotation (fig. 3 A) in parallel sagittal planes on the same transverse axis, and if they are moved as before through corresponding quadrants of the horizontal orbit perpendicular to their own plane of rotation till they meet in front, they will be rotating in reverse directions in the same frontal plane on parallel longitudinal axes. Here, again, the conjugate rotation in the first position has become reverse rotation in the second, as the globes have been moved through a quadrant of a horizontal orbit which is perpendicular to their own plane of rotation.

As soon as these principles are recognized in the model there can be no difficulty in applying them to the movements of the eyes in animals, the essential points of which the model represents. Rotation of the eyes may occur in any plane, but for purposes of investigation it is best to consider only three as we have done hitherto. In the model the globes can be moved through a complete quadrant, and their direction of rotation becomes absolutely reversed; in the animal the movement from the divergent to the parallel position is not a complete quadrant, and the direction of rotation, instead of becoming absolutely reversed, is only approximately so, and is, in fact, slightly oblique, one pupil moving slightly in as well as up, the other slightly out as well as down. In other respects the conditions are identical. I do not know whether many people are familiar with normal conjugate movements in divergent eyes, but Sir Victor Horsley and I were not till we saw them in the armadillo, and then we did not recognize immediately that they were conjugate; but on reflection it was obvious that they were so, and we found them constant in other armadilloes and in ducks. The characteristic response in all animals, as far as we know, to faradic stimulation of one dentate nucleus of the cerebellum is conjugate movement of the head and eyes to the side stimulated. There are all degrees of this movement under various conditions, sometimes of the head alone, sometimes of the eyes alone, sometimes of one eye only, but the typical response is the combined movement. We found it very clearly represented in the armadillo and also in the duck. But in both when one eye moved forwards the other moved back. Of course that must be so if they both move in the same direction. Suppose the left pupil moves forwards and the right back, it is obvious that both pupils are moving to the right: the eyes are rotating in the horizontal plane on vertical axes. If we imagine ourselves observing the pupil from the axis of rotation, in both cases it moves to the right, and if the eyes were brought forwards in a horizontal orbit (fig. 1) to the parallel position, the movement would be recognized at once as conjugate rotation to the right. We made a number of observations on rotation in all three planes in the armadillo and duck with similar results, *i.e.*, in conjugate rotation in the frontal plane (fig. 2A) one pupil moved up and the other down, but the eyes were rotating in the same direction in the same frontal plane on parallel longitudinal axes—it was conjugate rotation.

Similarly with conjugate rotation in parallel sagittal planes (fig. 3A). One eye appeared to the observer to be moving in the same direction as the hands of a clock, the other in the reverse direction. They were moving in the same direction, but the observer has to look at the eyes from opposite sides, and to him the directions are reversed. The same thing can be observed in the wheels of a dog-cart, which are a good illustration of conjugate rotation in parallel sagittal planes on the same transverse axis—exactly the same rotation as we are now considering in the armadillo. Suppose the wheels of the dog-cart are both rotating as in forward movement; if the observer regards the off-wheel from that side the top of the wheel is travelling to his right, in the same direction as the hands of a clock. If he looks at the near-wheel from the near side the top of the wheel is moving towards his left—the opposite way to the other and to the clock, but the wheels are moving in the same direction: their rotation is conjugate, only the observer regards them from opposite points of view. As to the changes in associated rotations in passing from the divergent position in the armadillo to the parallel position in the monkey, they will be obvious on referring to the model or the diagram already described. The orbit through which the eyes pass from one position to the other is a horizontal one, consequently conjugate rotation of the eyes on their own axes (fig. 1) in the horizontal plane in the first position will remain so in the second. But conjugate rotations in the frontal and sagittal planes (figs. 2 and 3), being perpendicular to the horizontal orbit in which they are moved from the first to the second position, will become reverse rotations in accordance with the rule which has been explained.

A review of these considerations appears to afford some support to the following summary of conclusions:—

(1) That animals possessing typical binocular vision, like the monkey, are descended from ancestors with divergent eyes.

(2) That these ancestors had acquired the varieties of conjugate rotation now exhibited by divergent eyes.

(3) That the conjugate rotation in the frontal and sagittal planes would become reverse rotations in the new position of the eyes, and being no longer useful were discarded, and new associated movements to produce conjugate rotations in the new position were acquired.

(4) That the supersession of the old habits by new ones must in the first instance have been directed by relatively high coördinating centres, and that, up to a certain stage of development, if this directing influence were removed there would be a tendency to revert to the old habits.

If these conclusions are at all justifiable it is possible that in animals with binocular vision some relics of that tendency still exist, and when the influence of the controlling centres is removed or interfered with the old habits occasionally assert themselves, and a reversion to the conjugate rotation of divergent eyes occurs.

The probability of this explanation of reverse rotation is apparently increased by its frequent occurrence under anæsthesia. It is frequently seen under anæsthesia alone; I do not know that it happens in animals without it, though it is possible it may do so. Sir Victor Horsley and I have records of a very large number of observations (amounting to some thousands) of movements of the eyes of various animals from stimulation of the cerebellar and other nuclei, and we have no record of skew deviation persisting in an animal after it has recovered from anæsthesia. It has often occurred under an anæsthetic before any operation has been begun, more often after stimulation of the cerebellum while the animal was still under an anæsthetic. In this respect it bears some resemblance to the conservative contracture of muscles, both flexors and extensors, with predominance of one group or the other, which often occurs under anæsthesia when interference with afferent paths or centres has apparently deprived the directing centres of the intelligence on which they depend. Like the deviations of the eyes these contractures commonly disappear or change with recovery from anæsthesia, and, like them, often take the character of some established association of movements like progression, where the limbs of one side are flexed and of the other extended. That two forms of reverse rotation, viz., those in the frontal and sagittal planes in animals with binocular vision, should be identical with normal conjugate rotation in the divergent eyes of their ancestors is interesting, and the acquisition through long periods of time, first of a habit of associating the superior rectus of one side with the inferior rectus of the other for a useful purpose, then in response to anatomical changes of position, which themselves formed part of the evolutionary scheme of more effective vision, the reversal of this habit and its complete supersession by a new automatism, and under certain conditions, of which removal of control and interference with afferent mechanism seem the chief, a temporary reversion to the earliest habit, form a striking sequence of events which deserve consideration in any estimate of the causes of reverse rotation in parallel eyes.

NOTE ON THE EXISTENCE OF REISSNER'S FIBRE IN HIGHER VERTEBRATES.

By SIR VICTOR HORSLEY, F.R.S., F.R.C.S.

(*From the Laboratory of Chemical Pathology, University College, London.*)

MORPHOLOGICAL study of the central nervous system has for a number of years been notably advanced on the interesting structure known as Reissner's fibre by the work of Porter E. Sargent, who has shown that in the teleostean it arises in the torus longitudinalis tecti, extending thence caudally along the central canal of the nervous system, and that it is probably present in all classes of vertebrates.

For a clear survey of the literature of the subject we are also indebted to Sargent, to whose papers [3], [4], [5] reference must be made for his discussion of the character of the fibre and its anatomical structure.

The importance of its relation to the habenular region having recently formed the subject of a communication by Professor Dendy suggested to me searching the various series of sections of apes' brains in my possession as a comparison with the lower vertebrates.

The physical character of the fibre, well described by Sargent, viz., its stiff elastic recoil, causes it to be readily lost in preparing sections of the central canal of the nervous system. Hence, I have been able to find it preserved in good lengths in one animal only, *Macacus cynomolgus*, in a series of sagittal sections stained by Marchi's method, cut especially thick; in this case a considerable clot in the central canal entangled the fibre and partly secured it *in situ*.

It is, however, not only the evidence of the occurrence of this interesting structure in the higher apes which leads me to publish this note, but also that the further question of the function of the fibre deserves closer attention from neurologists.

Naturally, the greatest deference is due to the opinion of Sargent,

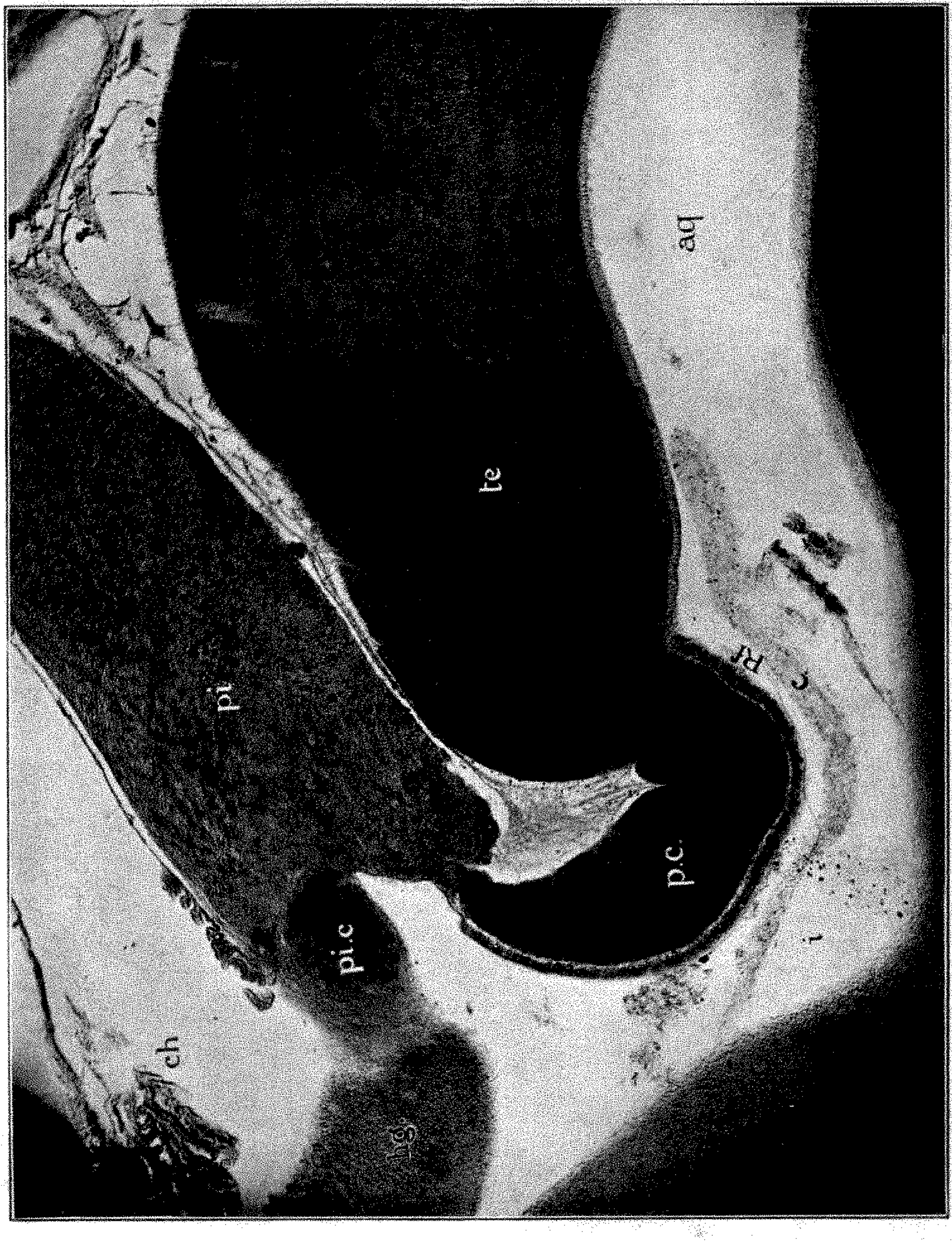


Fig. 1.

Macacus cynomolgus. Longitudinal section. ch, choroid plexus; hg., mesial surface of ganglion habenulæ; pi.c, commissura habenularis; pi, corpus pinealis; p.c., commissure posterior; te, tectum; i, iter; c, clot; Rf, letters placed at the broken end of Reissner's fibra, which extends forwards beneath the columnar epithelium as a wavy line into the clot; aq. aqueductus Fallopii.

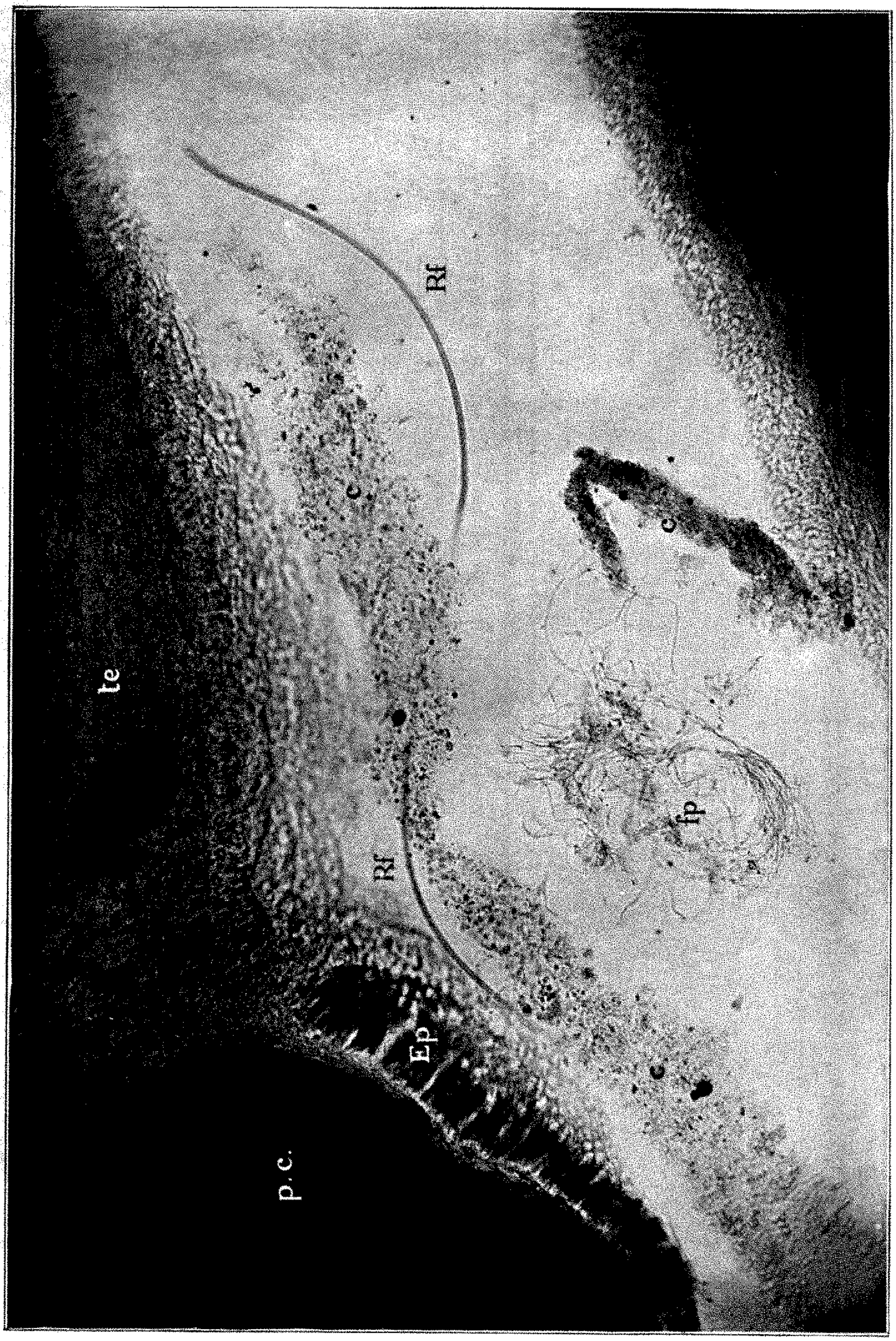


FIG. 2.

Macacus cynomolgus. Next section in the series to fig. 1. Reissner's fibre, Rf, entangled in the clot, c, continues into the aqueduct. Compare for artefacts the clots, c, c, and the filter paper fibres, f p. E p, ventral columnar epithelium (Dendy [1]).

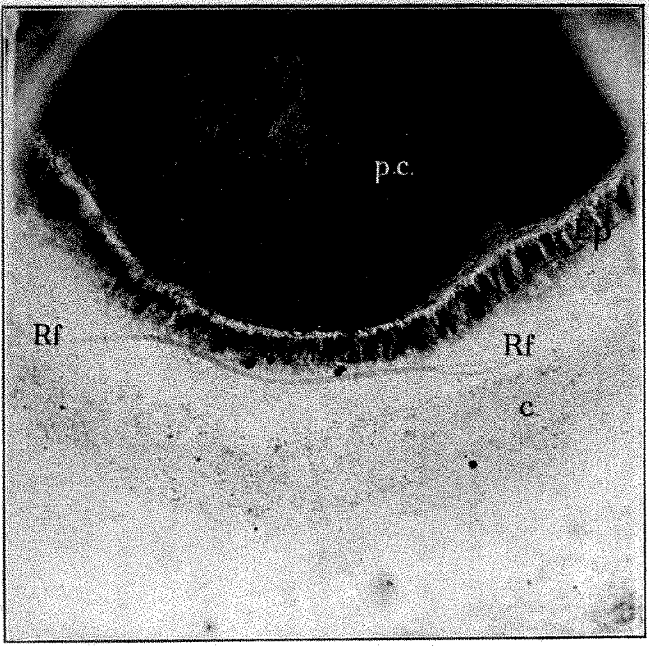


FIG. 3.

Macacus cynomolgus. Posterior half of Reissner's fibre, shown in fig. 1, more highly magnified. Lettering as figs. 1 and 2. The elastic recoil of the broken fibre is characteristically shown at the right hand end.

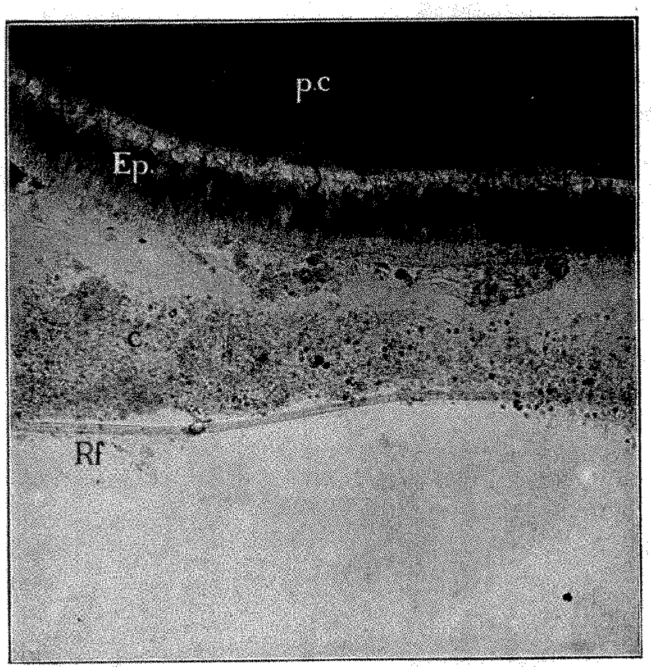


FIG. 4.

Macacus cynomolgus. The anterior half of Reissner's fibre, as shown in fig. 1, more highly magnified. The fibre, Rf, shows well (especially under a lens) the appearance of fibrillation or of a core, and reacts in staining more as an epithelial structure than a nerve fibre.

who has essentially made this subject his own; but even the study of his extremely interesting papers (especially [5]) does not produce conviction that the fibre is in fact an internuncial nerve tract which rivals or even exceeds in importance the tecto-spinal system, rather

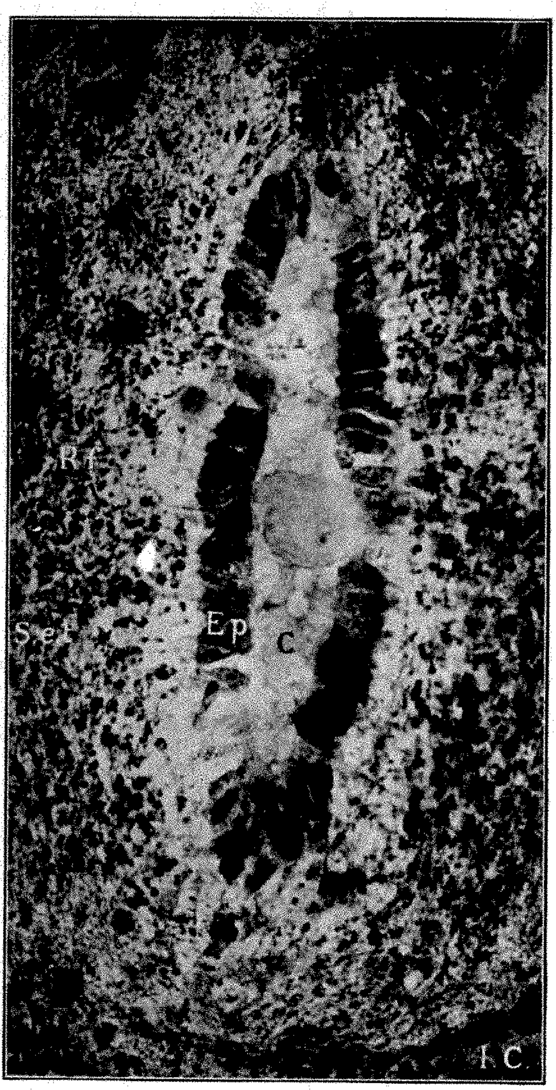


FIG. 5.

Macacus rhesus. Transverse section of spinal cord at the level of the first cervical segment highly magnified. The centre of the central canal is occupied by Reissner's fibre, the rest by altered blood-clot, C. The fibre shows a spot suggesting the existence of a core. The section has been lightly compressed. Ep, epithelium.

than a skeletal or ependymal structure. On this point, namely, the physiological function of Reissner's fibre, I venture to think Sherrington [6] has accepted somewhat prematurely the proofs that at present are before us of its being in the higher mammal an optic reflex nerve path.

As Sargent has abundantly established, Reissner's fibre begins by several or many roots of origin from a wide stretch of the ventral (ventricular) aspect of the tectum in the posterior commissural and habenular region. For its origin in the frog see [5]. He has shown that its attachments to the roof of the aqueduct extend from the habenular ganglion in front to the recessus mesocœli behind the caudal border of the posterior commissure. Here it arises in fish from the

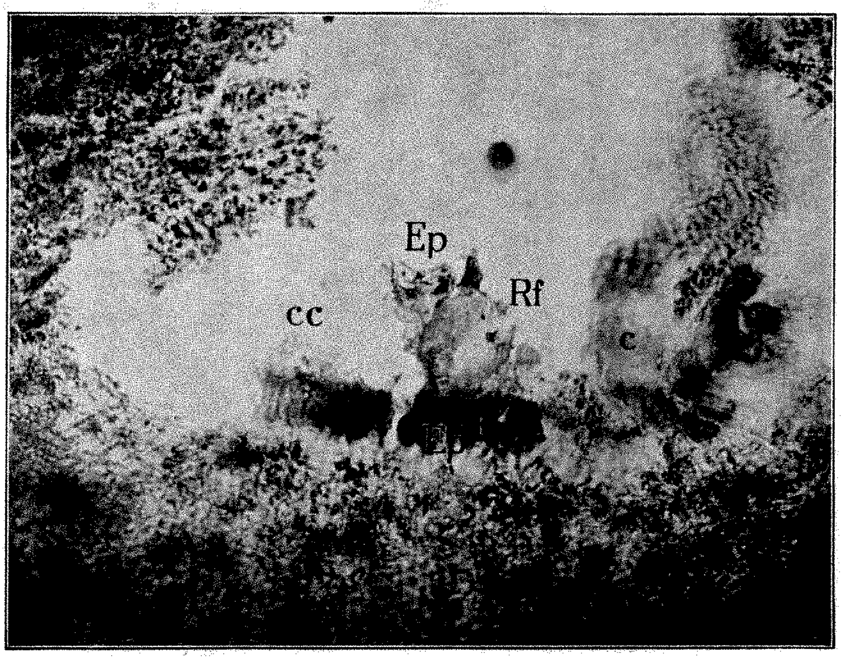


FIG. 6.

Macacus rhesus. A section close to that shown in fig. 5 dissociated by pressure, showing Reissner's fibre crushed, Rf. Its structure is seen to be unlike that of a nerve fibre, and the condensed peripheral border does not stain like myelin with the osmic acid. Ep, epithelium of central canal; cc, canalis centralis.

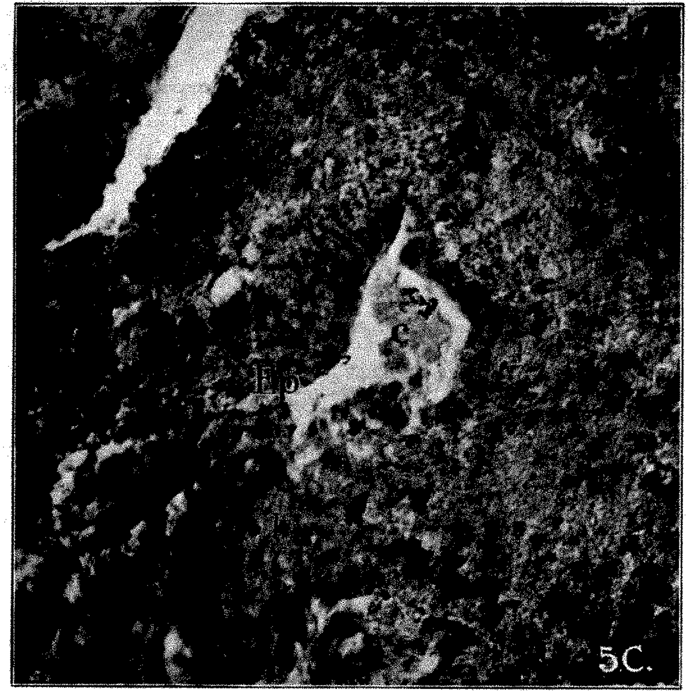


FIG. 7.

Macacus rhesus. Electrolytic destruction of the central canal of the spinal cord and of Reissner's fibre at the level of the fifth cervical segment. The ventral half of the canal is obliterated in the *débris* of the lesion, l. Some of the ependymal epithelium, Ep, is preserved. The canal is filled with clot, c, which had shrunk in fixing. The series of figures 7—13 show that though the fibre has been destroyed it does not degenerate like a nerve fibre or tract, either in an ascending or descending direction.

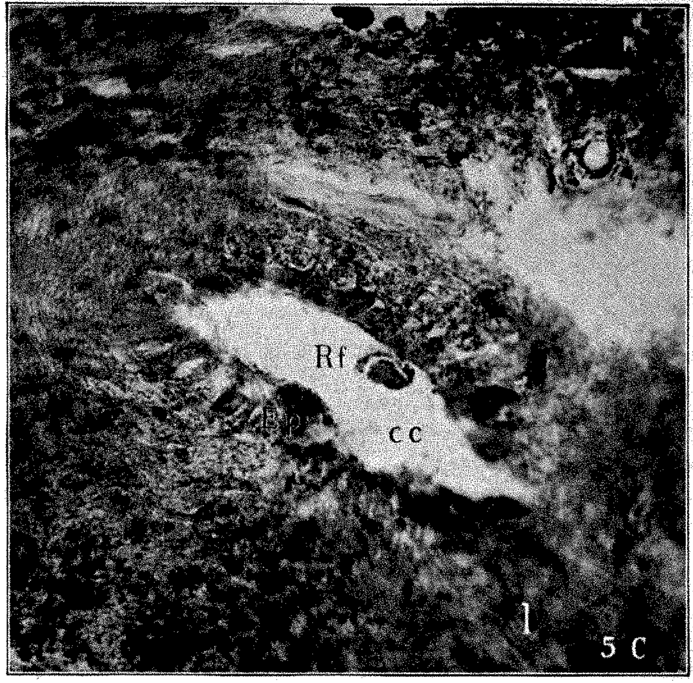


FIG. 8.

Macacus rhesus. Same experiment as in fig. 7. Section at level of upper part of fifth cervical segment showing destruction of the ventral ependymal epithelium by the lesion, l. The clot has dropped out of the central canal, c c, and Reissner's fibre, Rf, simply shrunken remains adherent to the epithelium by a little clot.

torus longitudinalis, and especially from the nucleus of large corpuscles (nidulus tectalis, Sargent), which has received various names, including the unfortunate expression *roof nucleus.* The fibre composed by the fusion of its roots of origin extends as a single structure down the iter, through the fourth ventricle and throughout the central canal of the spinal cord, giving off branches to the wall of the latter tube. The structure of the fibre is regarded by Sargent as consisting of axones covered by a myelin sheath.

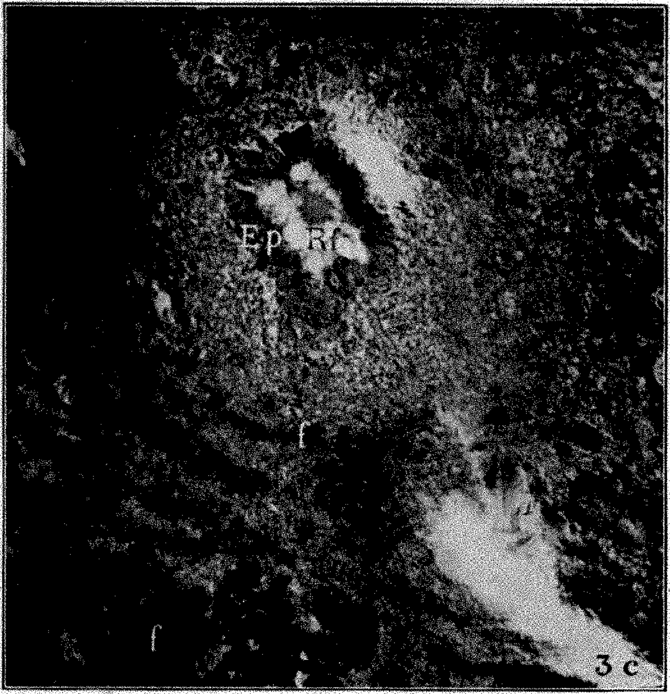


FIG. 9.

Macacus rhesus. Same experiment as in fig. 7. Section at level of third cervical segment. The central canal shows still much injury to the epithelium, E p, while Reissner's fibre, Rf, only shows shrinkage. Nerve fibres showing myelin staining are seen at f, f.

That the interior of the fibre often appears to be fibrillar is obvious, and is shown in figs. 1 to 4 (on examination with a lens), but neither the texture nor the appearance of the fibre resembles any nerve tract. Especially is this noticeable in the stiff resiliency of its structure, which is more characteristic of an almost chitinous or skeletal structure than that of a soft nerve fibre (see also figs. 5 and 6).

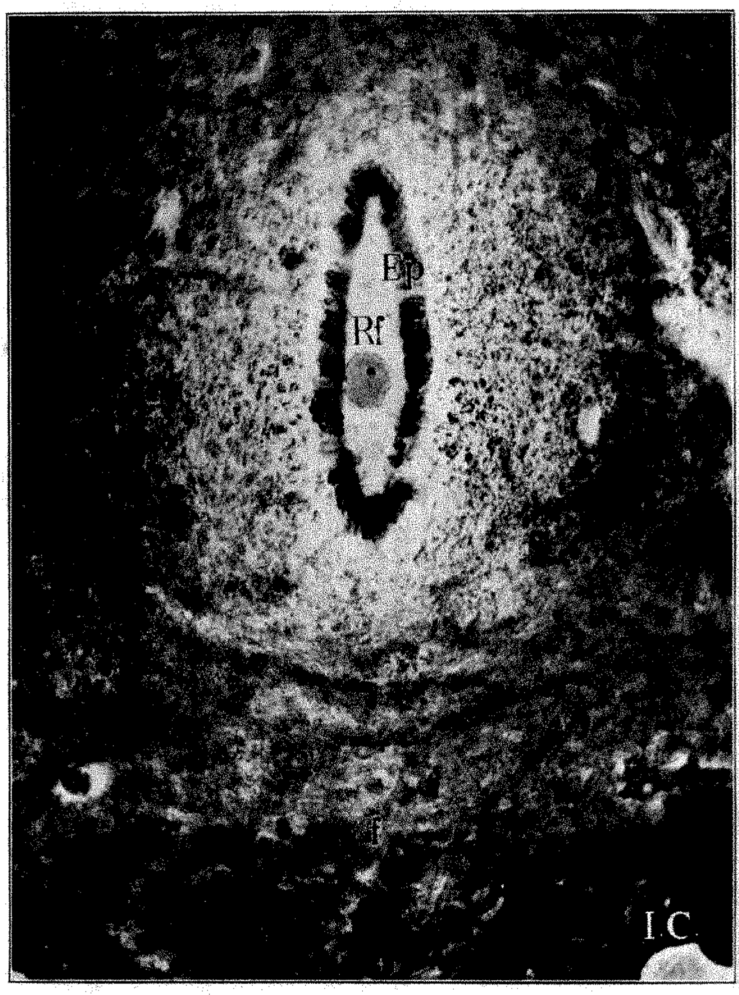


Fig. 10.

Macacus rhesus. Same experiment as in fig. 7. Section at level of first cervical segment. Reissner's fibre, Rf, is well seen in the canal, exhibiting its somewhat condensed periphery and the appearance of a core (not constant). Compare the diameter of the fibre in this figure with that in fig. 13.

As regards the existence of a myelin sheath, it is evident from the photographs that the osmic acid in fact stains the outer, or indeed any part of the fibre, less intensely than the normal nerve fibres, and the same is observable in other animals (*Macacus rhesus*; three individuals).

Moreover none of the figures given by the various authors writing on this structure appear to me to confirm the view that the outer part of the fibre is a medullary sheath, and this point, as well as the central connection and origin of the fibre, must receive reinvestigation, at any rate before we can assume that the fibre is in the higher vertebrate more than a residual structure.

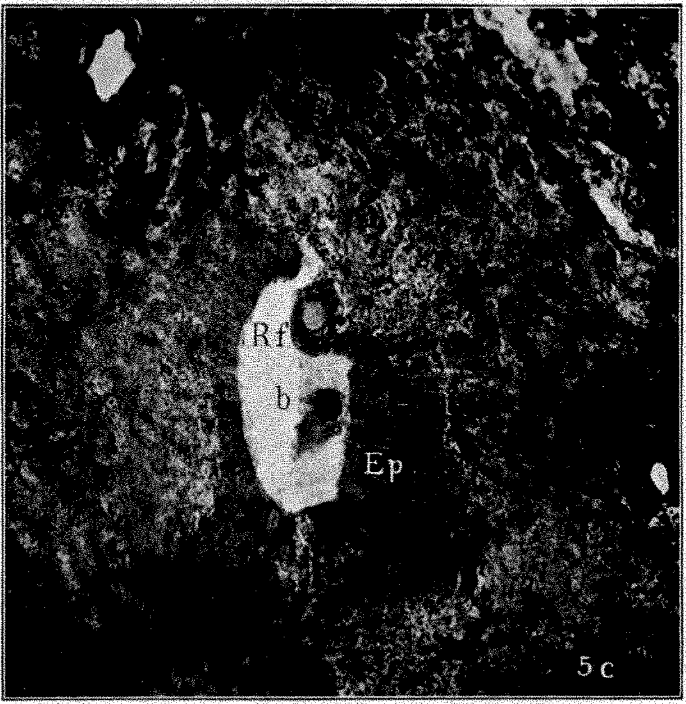


FIG. 11.

Macacus rhesus. Same experiment as in fig. 7. Section at level of lower border of fifth cervical segment. The epithelium of the central canal has been slightly injured over one-sixth of its circumference. Reissner's fibre, R f, is buried in the swollen epithelium. At b is a blood-clot, the hæmoglobin content of four or five red corpuscles being fused into the black mass in the centre. Reissner's fibre is unaltered, *i.e.*, not "degenerated."

Finally, I have recently obtained evidence which appears to me to be inexplicable if the fibre is to be regarded as a nerve bundle. This is the crucial test of degeneration. In a research which I am carrying on with Dr. McNalty, and in which I have made minute electrolytic lesions in the interior of the spinal cord, causing clots in the central canal and so fixing the fibre *in situ*, the following result has been obtained in a *Macacus rhesus*. The lesion destroyed in this instance the fibre at the level of the fifth cervical segment (fig. 7), but neither upwards nor downwards from this point does the fibre exhibit any degenerative or abnormal changes, except that of moderate shrinkage from the fifth cervical to the third cervical segment—parallel, in fact, to the longitudinal extent of the electrolytic lesion (*see* figs. 7 to 13).

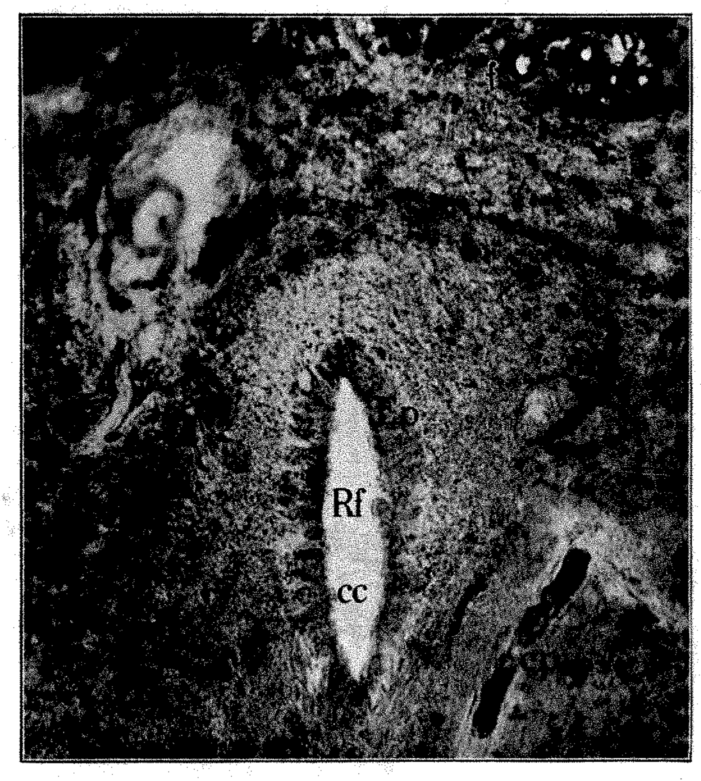


FIG. 12.

Macacus rhesus. Same experiment as fig. 7. Section at level of the second dorsal segment. Reissner's fibre, Rf, of normal appearance, lies between Rf and the ependymal epithelium. f, normal nerve fibres deeply stained with the osmic acid; cp capillary blood-vessel; cc, canalis centralis.

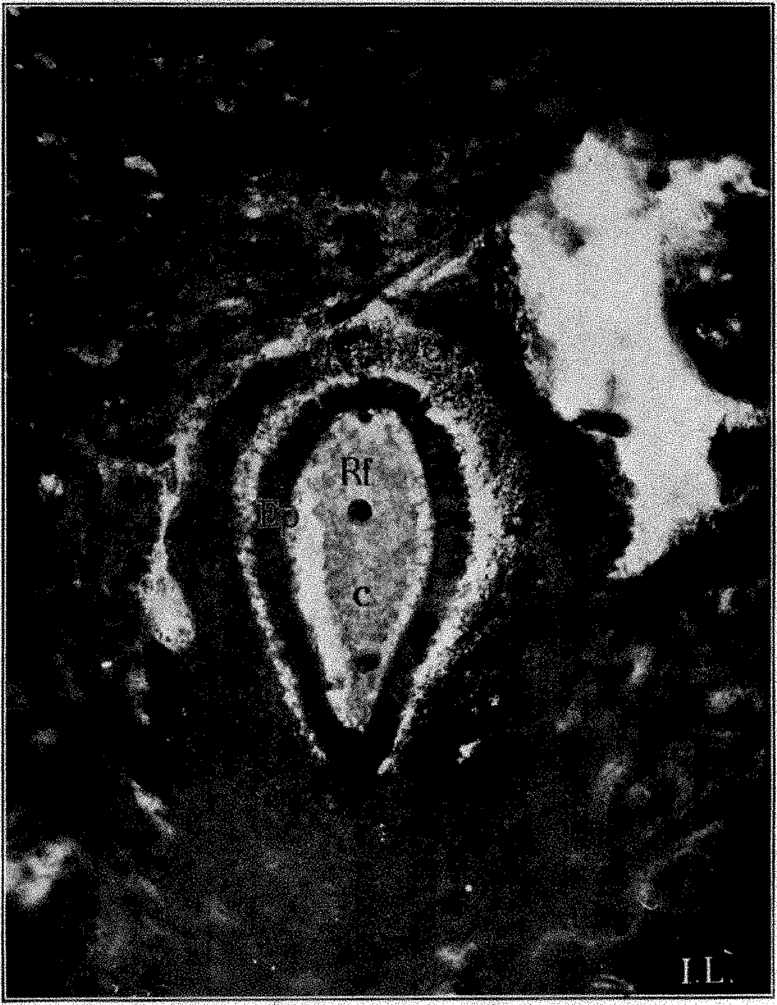


FIG. 13.

Macacus rhesus. Same experiment as fig. 7. Section at level of the first lumbar segment. The central canal is filled with clot, c. Reissner's fibre, normal in appearance and size, is seen below Rf. The tapering of the fibre (Sargent) from the first cervical (fig. 10) to the first lumbar segment is well shown in this series. Ep, epithelium.

SUMMARY.

(1) Reissner's fibre is present and well marked in *Macacus cynomolgus* and *rhesus*.

(2) Reissner's fibre in its normal structure and in its not reacting to injury does not resemble a nerve fibre or tract.

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[2] NICHOLLS. *Nature*, February 13, 1908, p. 344.

[3] SARGENT. *Anatom. Anzeig*, 1900, Bd. xvii., S. 32 (for literature and general course of the fibre).

[4] *Ibid.* "Mark Anniversary Volume," New York, 1903, p. 399 (for description of the torus longitudinalis and origin of the fibre).

[5] *Ibid. Bull. Mus. Comp. Zool. Harv. Coll.*, 1904, vol. xlv., No. 3, p. 129 (principal paper; full title: "The Optic Reflex Apparatus of Vertebrates for Short Circuit transmission of Motor Reflexes through Reissner's Fibre, its Morphology, Ontogeny, Phylogeny and Function.—Part I. The Fish-like Vertebrates.")

[6] SHERRINGTON. "The Integrative Action of the Nervous System," 1906, p. 329.

A CASE OF AMYOTONIA CONGENITA.

By THEODORE THOMPSON, M.D., M.R.C.P., F.R.C.S.,

Assistant Physician to the London Hospital and to the Hospital for Sick Children.

E. B., a female infant aged 14 months, was brought to the Hospital for Sick Children, Great Ormond Street, on July 15, 1907. The mother complained that the child was flabby and drowsy. A doctor had told her that the baby was smaller than it should be and was suffering from rickets.

Born at full term, the child was breast fed until 11 months old; she was then weaned and fed on milk, bread and butter, and gravy. She weighed 10 lb. at birth and 17 lb. at 14 months old. The mother had to have chloroform when the child was born, but as far as she knew no instruments were used.

The first thing noticed to be wrong with the child was that it did not begin to sit up at 3 months old as the other two children had done. It was not until 13 months old that any attempt to sit up was made. The child's legs had always been flabby and loose. There had never been any fits, and no trouble had occurred with the bowels or digestion, except that occasionally the motions had a strong smell. When 12 months old the baby had an attack of measles, and since then she has suffered somewhat from cough.

The mother had been married six years, and had two other girls, aged 5 and 3. Both were strong and healthy. There was no history of nervous disease in either the mother's or father's family.

Present condition.—The child is rather small for her age, but is well nourished. Her intelligence seems normal. The skin is smooth and healthy. The head measures 17½ in. in circumference, and the anterior fontanelle is almost closed. The bones are normal and there is no enlargement at the epiphysial lines. The heart and lungs are normal, and neither the liver nor the spleen is enlarged. The abdomen is not unduly protuberant.

Profound changes are found in the condition of the nervous system.

The calves are soft and velvety to the touch, and it is impossible to define the outlines of the muscles when they contract, either voluntarily or on electrical stimulation. In the lower limbs no definite muscle groups are affected, but both the extensor and flexor muscles of the legs and the extensors of the thighs are soft and flabby. The hamstrings and the adductors of the thigh do not seem to be affected and their surfaces can easily be defined beneath the skin when they contract. Neither the abdominal nor the intercostal muscles are affected, and the movements of respiration are quite normal. There is a kyphotic curve extending from the top to the bottom of the spine, and even at 14 months old the child cannot sit up without help. There is no winging of the scapulæ, and the outline of the deltoid muscle can be felt beneath the skin when it contracts. The other muscles of the arms, forearms and hands are wasted, soft and flabby. The muscles of the neck are weak and the child's head often wabbles over to one side. The facial muscles are unaffected.

The loss of bulk of the muscles is considerable, but is not of the extreme degree seen in the dystrophies or in muscular atrophies of spinal origin. Muscular power seems everywhere less than normal, but the child can grasp firmly. The most marked feature is a loss of tone in the muscles, so that an abnormal degree of passive movement is possible at the various joints. Thus the dorsum of the foot can easily be made to touch the shin without causing the child any pain. A slight degree of genu recurvatum can be produced, the amount of hyperextension being limited by the ligaments of the joint. The extreme mobility at the ankle is well shown in fig. 1. The dorsum of the hand can be bent backwards so as to touch the extensor surface of the forearm, and the forearm can be slightly hyperextended. These extensive passive movements must imply a corresponding enlargement of the joint surfaces, but possibly this occurs secondarily to the laxity of the muscles. Fig. 2 shows the hyperextension at the wrist and elbow.

The electrical reactions in the muscles are interesting. Faradic excitability is diminished. Measured by Dr. Reginald Morton's faradic alternator, a contraction can just be obtained with a current of 1·4 ma., whereas a normal muscle gives a brisk response with 0·6 ma. Another feature is the ability of the child to bear strong faradic currents without discomfort. Thus she makes little remonstrance when the muscles are tested with a faradic current of 4 ma., a strength which on this instrument would make a normal child scream with pain. Galvanic excitability is likewise diminished, but the response is quite a brisk twitch and not at all sluggish. Thus contraction is first obtained with a current of 2·5 ma., whereas from normal muscle a brisk response can be obtained

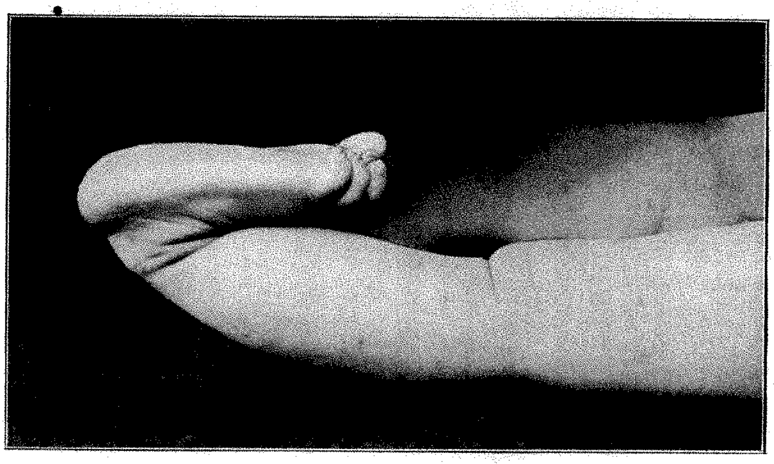

FIG. 1.

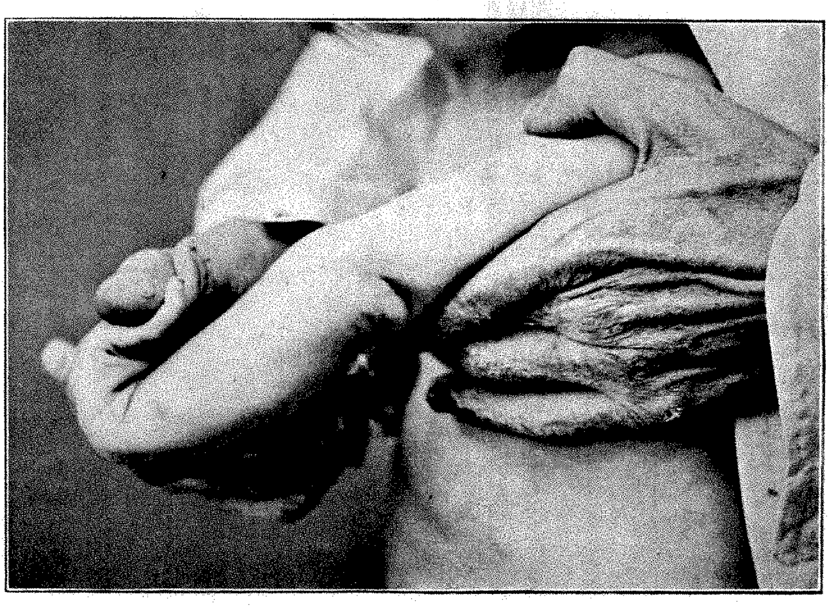

FIG. 2.

with 1 ma. There is no alteration in the polar reactions, the kathodal closing contraction being as strong as the anodal closing contraction.

There is no alteration in the faradic or galvanic excitability of the nerve trunks.

Sensation.—Sensation to touch is normal. When pricked with a pin the child begins to cry and strongly resents it. This is in sharp contrast to her apathy when tested with the strong faradic current, and suggests that possibly the peripheral sensory mechanism in the muscles is undeveloped, while in the skin it is not affected.

Reflexes.—The knee-jerks were obtained on both sides, but no response could be elicited on stroking the soles.

Progress.—The child was treated by massage and tonics. When seen in November, 1907 (*i.e.*, when 18 months old), she had greatly improved. She could sit up alone and also made an attempt to stand. When doing this the dorsal kyphotic curve disappeared and there was some lordosis in the lumbar region of the spine. She could say a few words and seemed to be progressing favourably.

REMARKS.

The absence of any sign of involvement of the brain and spinal cord, the general distribution of the lesion and the character of the electrical reactions, point to the muscles themselves as being the seat of the disease. The distribution of the affected muscles is markedly different from that seen in the muscular dystrophies. In the latter the muscles of the hip and shoulder girdles are generally affected, while the muscles of the forearms and legs are rarely involved. Moreover the dystrophies begin to show symptoms at a much later age than in the case of this child, in whom weakness was noticed at 3 months old. There remains the possibility that the muscular weakness may be due to some general condition such as rickets, in which disease the muscles may occasionally show a remarkable loss of tone. The early age of onset, the absence of all bony deformity, and the correct feeding adopted in this case all seem to exclude rickets as a possible cause. It may be that some of the cases described as the "acrobatic type of rickets" are examples of this disease.

The main feature of this case seems to be a loss of muscular tone, possibly due to a defect in the sensory mechanism in the muscles, and it seems to fall in the group of cases of congenital muscular atony first described by Oppenheim.

A CONTRIBUTION TO THE STUDY OF APRAXIA
WITH A REVIEW OF THE LITERATURE.

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INTRODUCTION.

THE condition which has come to be known as apraxia or dyspraxia, or the inability of an individual who has neither motor nor sensory paralysis, nor ataxia, to perform certain familiar purposive movements, is by no means a new discovery. A cursory glance over not a few more or less old clinical descriptions of cases of aphasia will reveal instances of this form of disturbance of cerebral function, where phenomena undoubtedly of an apraxic nature are mentioned without any specific term being applied to them. The more critical analysis, within recent years, of the symptom-complex of aphasia has led to wider recognition of the frequency and deeper appreciation of the significance of certain changes in the higher realms of cerebral function, and with this appreciation has arisen the necessity for the employment of new expressions to serve for these changes. We do not find the terms agnosia, asymboly, or apraxia in common use until we come within measurable distance of the present epoch of neurological activity. By agnosia is meant failure of intellectual recognition where there is integrity of primary identification; that is, where there is no impairment of simple perception. Thus, in the field of vision, if I see an object but fail to recognize it, I am suffering from a form of visual agnosia, or mind-blindness. If I hear a familiar sound, but fail to recognize it, I am suffering from a degree of auditory agnosia, or mind-deafness. If I feel an object in my hand, but am unable to recognize it by touch, my condition is one of tactile agnosia, frequently, but erroneously, called astereognosis. Similarly, we may be unable to recognize objects presented to us by other sense avenues; we may fail to recognize a familar smell or a familiar taste, though we taste and smell readily enough. Apraxia in its widest sense is, in a general way, at once a disturbance of perception and a disturbance of volition, or, rather, it may be the outcome of a disturbance of perception, or of volition, or of both. The defect may be psychosensory, or intrapsychical, or psychomotor in origin; hence the intimate relation of apraxia to the various forms of agnosia. If I cannot recognize an object presented to me, clearly I shall be unable to indicate its use; if a patient is handed a pencil and fails to perceive it is an instrument for writing, he may when told to use it put it in his mouth as though it were a cigar. In this instance there is obviously a psychosensory defect, and the ensuing apraxia is of a sensory type; it is apraxia of sensory origin, consecutive to visual agnosia. But, inasmuch as he believes the pencil is a cigar, the patient employs it correctly *quâ* cigar; in other words, the apraxia is not of a motor type. Should he recognize the pencil—and indeed he may say it is a pencil, and say further that it is used for writing—but when asked to use it, should he fumble with it in endlessly futile ways, he is exhibiting motor apraxia. These are very simple forms of apraxia, but one meets with still simpler instances. A hemiplegic patient may be unable to protrude his tongue when requested to do so, but that there is no paralysis is patent when he unconsciously licks his lips with that organ. The motor aphasic, in a sense, is affected with apraxia of his speech musculature. On the other hand, apraxia may become highly complex as the result of special psychical defects or of a general mental deterioration; we shall see instances of this again. Sometimes the apraxic patient cannot make a given movement or series of movements unless he has the object in his hand with which the movements are associated—thus he cannot initiate the movement of counting out money; but put six pennies into his hand and he will count them out forthwith.

It is apparent that apraxia of sensory or motor or mixed type may occur in very varying conditions. Its association with different forms of aphasia is, of course, not infrequent, and the analogies between the two furnish an instructive subject for discussion. Apraxia is common in those forms of mental alteration which are the outcome of cerebral vascular degeneration; it is found in certain cases of intracranial tumour. It is seen in post-epileptic confusional states, also in the dementia of alcoholism and other toxic conditions. It may be unilateral or bilateral, transient or persistent, partial or complete. In making a diagnosis of apraxia the possible existence and influence of hysteria, of central or peripheral ataxia, of gross motor or sensory impairment, must be considered and excluded.

Our knowledge of apraxia is of relatively recent date; from the German school in particular have come many noteworthy contributions to the study of the subject, and the theoretical considerations with which Continental observers have enriched it have been the natural sequence of many painstaking clinical examinations of patients where apraxic phenomena have been discovered. It is of significance in this connection that Liepmann's classic case of apraxia, which will remain a monument of clinical insight and examinational ingenuity, was at one stage considered by superficial observers to concern so hopeless a lunatic as to promise little in instructiveness; yet it has come to be regarded as a model for future workers in this field.

In view of the desirability of a clear understanding as to the import of certain terms, and in face of the still existing discord in the interpretation of facts, a historical retrospect may not be devoid of value.

HISTORICAL.

There can be no doubt that one of the first to observe the phenomena with which we are dealing, and to give them a special name, was Hughlings Jackson, although (with the solitary exceptions of Pick [68] and Lépine [36]) none of the Continental writers alludes to the fact. In a footnote on the first page of his "Studien" Pick remarks: "Es erscheint mir als ein Akt historischer Gerechtigkeit, auf die nur von Lépine beachtete Tatsache hinzuweisen, dass Hughlings Jackson wohl als einer der ersten die Störung klinisch erkannt hat; in einem zeitlich von mir nicht genauer zu fixierenden Aufsatze, der aber gewiss in die Siebzigerjahre zurückreicht, betitelt 'Case of Large Cerebral Tumour without Optic Neuritis, and with Left Hemiplegia and Imperception,' beschreibt J. unter der letzteren Bezeichnung die als Asymbolie oder Agnosie bezeichnete Störung." The patient referred to in this paper was seen in 1875, and the following passages may be quoted from the article [27] :—

"The first symptoms were those of what I call Imperception. She often did not know objects, persons, and places. . . . Now and then she would do odd things; she would put sugar in the tea two or three times over; she made mistakes in dressing herself; put her things on wrong side before, and did little things of that kind. . . . Imperception is a defect as special as aphasia. The case did not correspond, however, to loss of speech, but to defect of speech. There was partial imperception."

Failure to recognize objects (instances are given) in this case clearly points to a degree of visual agnosia, or mind-blindness, which is closely allied to sensory (agnostic) apraxia. The fact that the patient made mistakes in dressing herself is of interest; it is a defect to which I shall refer in a subsequent case.

But earlier still, in 1866, we find the following significant passages in a paper by Dr. Jackson, entitled "Remarks on those Cases of Disease of the Nervous System in which Defect of Expression is the most striking Symptom" [25] :—

"In some cases of defect of speech the patient seems to have lost much of his power to do anything he is told to do, even with those muscles that are not paralysed. Thus a patient will be unable to put out his tongue when we ask him, although he will use it well in semi-involuntary actions—for example, eating and swallowing. He will not make the particular grimace he is told to do, even when we make one for him to imitate. There is power in his muscles and in the centres for coördination of muscular groups, but he—the whole man, or the 'will'—cannot set them agoing. Such a patient may do a thing well at one time and not at another. In a few cases patients do not do things so simple as moving the hand (*i.e.*, the non-paralysed hand) when they are told. . . .

"One of my patients in the London Hospital had power only to say 'yes' and 'no.' . . . He had lost power to execute, not all movements, but those movements which are most artificial. . . .

"A few months ago a patient came under my care who could only say 'Pooh! pooh!' and an examination of his eyes was altogether impracticable. He made efforts, but he never did what I told him, whether it was to look in a particular way or to keep his eyes still. Instead of opening them he would open his mouth, or screw up his face, or shut his eye, and could not be got to look in any particular direction, although he seemed on the alert to act, and was all the time doing something with his muscles. . . .

"A speechless patient who cannot put out his tongue when told will sometimes actually put his fingers in his mouth as if to help to get it out; and yet not unfrequently, when we are tired of urging him, he will lick his lips with it. . . ."

One could not desire more apt clinical illustrations of pure motor apraxia than those thus figured by Dr. Jackson more than forty years ago.

In another paper (1878), entitled "Remarks on Non-protrusion of the Tongue in some cases of Aphasia" [28], we find the subjoined sentences:—

"The non-protrusion of the tongue is a thing of great scientific interest; considered along with some other symptoms of aphasia, it gives us a clue to the physiology of the whole of aphasia. . . .

"Some people are unable to draw in their breath deeply when told to do so during stethoscopic examination; we have to tell them to cough. It is next to impossible to get some patients to frown, as in suspected one-sided facial paralysis, even if we make a frown for them to imitate. . . .

"I have seen a patient who usually sat up in his room, whose face looked intelligent, who was cheerful and merry, and who seemed to understand all I said to him, but who could not put out his tongue when he tried. His daughter remarked that he could put the tongue out, as she expressed it, by accident, and added, as an illustration of her meaning, that when anyone was leaving him he could say 'good-bye,' but that he could neither put out his tongue nor say 'good-bye' if he tried. She further remarked that the patient would sometimes swear, but he could not repeat the word when he tried. She asked him to utter the explosive sound when I was there, saying it herself for him to imitate. He laughed, and shook his head. . . .

"All the above superficially different phenomena are fundamentally alike; they all show reduction to a more automatic condition."

It is abundantly clear from these extracts that Dr. Jackson not only recognized the importance and appreciated the significance of the condition known to-day as apraxia, but also advanced a theory of its causation, and when we remember that he observed and drew attention to the facts as long ago as 1866, we realize to what a remarkable extent he was ahead of his time.

Other early instances may be referred to. Von Monakow [56] mentions the case of a player on the clarionet who became aphasic, and thereafter was unable to put his lips into the position for blowing the instrument unless he actually had the mouthpiece in his mouth. Another motor aphasic was unable to blow into the air, though he could blow away ashes or dust. Bernheim [4] observed a characteristic case in 1883, where the failure of the patient to use objects correctly was noted and described as "une cécité psychique des choses." Griesinger [18] remarked how frequently an aphasic is unable to put his hand on a particular part of his body on request, and will touch his nose instead of his ear, &c. He regarded the mistake as due to confusion or perversion of movement, whereas Kussmaul [34], observing similar errors, thought they were due solely to confusion of words. Wernicke [82] had occasion, in 1884, to observe a patient without aphasia, but with loss of cutaneous sensation, who could not perform certain movements with his right hand if his eyes were shut. This uselessness of the arm was attributed to a loss of touch images; the failure to carry out more complicated acts with eyes closed was thought to follow from a loss of the corresponding ideas of movement.

In 1882 Westphal [83] published a carefully observed case, in which a patient who had considerable loss of the sense of position and of passive movement in the right upper extremity also exhibited a peculiar clumsiness in making use of it, even with his eyes open. Westphal considered the condition to be more than mere ataxia, and attributed it to a loss of kinæsthetic memories. In this way it may be likened to the *Seelenlähmung* of Nothnagel, to which we shall refer immediately.

Finkelnburg [14] was the first to employ the term "asymboly." Aphasia signifies inability to understand and to use certain conventional signs, viz., speech signs, and Finkelnburg noticed that many aphasics had lost other conventional signs; one of his patients could no longer understand the meaning of the symbols in the Roman Catholic Church service or of various business and political forms and signs. For all-types of defect of sign-recognition he used the term asymboly. But under this conception rather too much was gathered when he made it include cases of failure to recognize places and persons, *i.e.*, where not conventional signs, but the images of objects were concerned. Wernicke adopted this latter view of asymboly, and elaborated it to mean the loss of the memory pictures for an object. Thus patients with asymboly, in Wernicke's sense, can see, and hear, and feel, but impressions so gained are strange, and therefore useless, since they cannot recognize objects again by these means. They consequently show a lack of initiative; they cannot turn new sense impressions to account, which is the mainspring of action.

But the meaning of "conventional sign" attached to the word symbol prevented the general acceptance of asymboly in Wernicke's sense. Freud [16] suggested the word "agnosia" for defect in object recognition. Kussmaul, Starr and Pick [63] were the first to use the word "apraxia," but not in the present-day sense. Allen Starr [75] published a paper in 1888 on the varieties of apraxia and aphasia, in which the following definition is given: "It is found that each or all of the sensory organs, when called into play, may fail to arouse an intelligent perception of the object exciting them. For this general symptom of inability to recognize the use or import of an object the term apraxia is employed." And again: "To test for apraxia it is only necessary to present various objects to a person in various ways and notice whether he gives evidence of recognition." He quotes nine cases drawn from the previous literature, in all of which "power to recognize objects seen was lost." It is perfectly clear from Starr's account that his apraxia is nothing else than a limited visual agnosia, as we should call it to-day. Kussmaul used the word in more or less the same way. Laquer (1888) [35] said of an apraxic patient: "Es war ihr das Verständniss für den Gebrauch der notwendigsten Dinge verloren gegangen." The instances of this apraxia that he records show that the condition was really an agnosia, or imperception in Jackson's sense. Meynert [55] alone adhered to the opinions of Wernicke, and supported his contention in the following way: In various cortical centres there is for one and the same object a symbol, a sign by which it can be recognized. The loss of the sign of the object is asymboly. On the motor side the use of the object is associated with this sign of recognition, so that asymboly reveals itself in the patient's inability to make use of the object. A lesion in the central convolutions which hinders the awakening of the innervation memories (kinæsthetic images) of movements of the upper extremity will cause motor asymboly. Meynert's sensory asymboly corresponds to Wernicke's asymboly, Freud's agnosia, and the apraxia of others, while his motor asymboly is similar to Nothnagel's *Seelenlähmung* (see below), but is not, however, identical with the apraxia or motor apraxia that Liepmann, as we shall see directly, has so thoroughly investigated and established.

Heilbronner [21] used the term asymboly in the sense of sensory asymboly or agnosia. At a congress in Breslau in 1894 Bonhoeffer [6] showed a patient whose state he described as one of mind-blindness with asymboly; in addition to complete sensory asymboly, the patient exhibited an extraordinary helplessness in carrying out purposive movements, many of which were curiously distorted or perverted. In this instance there was motor apraxia, although the reporter does not employ the term. At the same congress Heilbronner [20] demonstrated a case of asymboly, as he called it, yet no mind-blindness, no sensory defect of any kind, existed. His patient gave the impression of being able to perform any movement-complex, but he always became confused in its performance. As there was no motor defect to cause a motor asymboly (in Heilbronner's sense), the author described the condition as "conduction asymboly" (*Leitungsasymbolie*). We shall explain Heilbronner's views at a later stage. One reason why Meynert's motor asymboly is unsatisfactory is that the clinical case on which he based his views was an unfortunately complicated one, as the patient suffered from a degree of mind-blindness, of motor paralysis, and of ataxia. These are three causes of impaired use of a limb which have nothing to do with motor asymboly. Meynert thought the condition of his patient was intimately allied to what Kussmaul had called apraxia, but a reference to that author shows that he considered failure to recognize objects as the fundamental element in apraxia, *i.e.*, his apraxia and *sensory* asymboly are more or less analogous.

Closely connected with the conception of apraxia is the "mind-palsy" (*Seelenlähmung*) of Nothnagel [62]. Following on lesions, in the parietal lobes, of the cortical areas for motor memory-pictures, the patient's arm under certain conditions, such as when the eyes are shut, became useless. He could not innervate it adequately by reason of his loss of the kinæsthetic images of the range and form of individual movements. This mind-palsy is a more limited disturbance of function than apraxia, for the apraxic patient cannot use his arm properly though he has the help both of eye and ear. In Bleuler's [5] case the patient could perform some movements with his eyes open which were impossible if he closed the latter; similarly in cases described by Bruns [9] and by

Anton [3]. Evidently we have here to do with an impairment of motility, a real palsy. Voluntary movements are diminished; in apraxia they are perverted. It may be noted, moreover, that Bruns [9] (and Bleuler, too) used the term *Seelenlähmung* to indicate cases where there was almost complete uselessness, or even immobility, of the limb, with no actual paralysis and no perversion of movement. These fall into the category rather of akinesia, therefore, than of apraxia.

A great impetus was given to the study of the subject by the publication, in 1900, of Liepmann's [40] case of unilateral apraxia. As has been already noticed, the term apraxia was at first proposed to signify the misuse of objects from failure to recognize them, though Freud had seen the advantage of calling this condition agnosia. To Liepmann must be assigned the credit of having elaborated the conception of a true motor apraxia, a defect in the use of objects, though they are perfectly recognized. He warmly advocated the restriction of the word apraxia to this form alone, considering agnosia preferable to sensory apraxia. If we are to regard every objective perversion of action, from whatever preceding cause, as apraxia, then the conception becomes unwieldy. We may call the blind apraxic because of their uncertainty, their running against objects; the word-deaf must be apraxic; the lunatic who mistakes his friend for an enemy and shoots him is apraxic. Thus conceived—for we must remember that we can gauge the psychical processes of the individual chiefly, if not entirely, by their motor exteriorization—the term becomes valueless. From the minute analysis of his own patient, Liepmann ventured to define motor apraxia as "incapacity for subjectively purposive movements of the limbs, with conservation of the power of movement." The apraxic subject is handed a cigar and asked to indicate its use; he knows it is a cigar, and the idea in his mind, his purpose, is to smoke it; he cannot translate this subjective purpose into action, and fumbles with the cigar; he is unable to perform subjectively purposive (*zweckgemäss*) movements. The agnosic patient, on the other hand, is given a toothbrush, and asked to show how it is used; he thinks it is a cigar, and accordingly the idea in his mind is to smoke it, which he proceeds to do; his movements, therefore, *are* subjectively purposive. If the idea in the patient's mind be absurd or grotesque, and if it be translated into action, the movements are not objectively purposive (*zweckmässig*)—in fact, they may appear objectively purposeless—though they may be, and are, subjectively purposive (*zweckgemäss*).

Liepmann [43] devised a fresh classification of the disturbances of cerebral function which interest us here as follows:—

(1) *Agnosia*—subdivided into :—

- (*a*) Mind-blindness.
- (*b*) Mind-deafness.
- (*c*) Tactile agnosia (*Seelentastlosigkeit, Tastlähmung*).
- (*d*) Gustatory agnosia (*Seelengeschmacklosigkeit*).
- (*e*) Olfactory agnosia (*Seelengeruchlosigkeit*).

Word-blindness (and it, in turn, has various subdivisions) is a partial mind-blindness. Any of these may be met with separately. A combination, in varying degree, may produce a result equivalent to Wernicke's asymboly, Meynert's sensory asymboly, sensory apraxia (a term to be avoided), Jackson's imperception.

(2) *Ideational apraxia.*—If, as a sequel of want of attention, or imperfection of memory, or deficient retentiveness, or for other reasons, the separation of the main idea of action into its component ideas of action is impaired, then the movement that results is conditioned by the erroneous component ideas, and ideational apraxia ensues. Ideational apraxia is linked more to agnosia than to motor apraxia, and is nearly always present with the former. In this type the faulty ideational, intrapsychical process is alone responsible for the apraxia.

(3) *Motor apraxia.*—If there is an interruption between the main idea of action as a whole and its carrying into effect as a whole, *i.e.*, between the idea of the movement and the innervation of the movement (with which, according to Liepmann, is associated the kinæsthetic element in the idea), the outcome is motor apraxia.

At an International Congress for Psychiatry and Neurology, held at Amsterdam in 1907, Liepmann [50] approached the subject from a rather different standpoint, and suggested the following four varieties of defective motility in a limb :—

(1) The muscles of a limb may not be paralysed, but the patient may be able to make very little voluntary use of them (*Willenslähmung; Seelenlähmung* in Bruns' sense).

(2) The limb may not be paralysed, but the patient may have lost certain combinations of movements which he formerly had acquired; delicate movements may be impossible, and the remaining movements awkward and unskilled. This variety is akin to cerebral ataxia in the strict sense, depends on the loss of kinæsthetic images of limb movements, and may be called "limb-kinæsthetic apraxia" (*gliedkinetische Apraxie*). This is identical with Meynert's motor asymboly, Nothnagel's *Seelenlähmung*, and, as we shall see, Heilbronner's cortical apraxia. In that form of "mind-palsy" where the patient is unable to use a limb unless the eyes are open there is loss not merely of kinæsthetic images,

but also of kinæsthetic impressions, so that he has to depend on his visual memories of movement.

(3) Limb-kinæsthetic memories are preserved, but isolated from other association fields, or not in sufficient touch with them. Ideational processes and kinæsthetic memories are severed. This is motor apraxia *par excellence*, or ideo-kinæsthetic apraxia.

(4) Limb-kinæsthetic memories are normal, and in normal association with other areas in which arises the mental "sketch" or "draft" of an act, but this ideational plan is itself defective, and the subsequent movement betrays the fact. This is ideational apraxia, identical with Pick's ideomotor apraxia.

We owe to Arnold Pick, of Prague, various noteworthy contributions to the study of apraxia. As long ago as 1892 he applied his analytical ingenuity to the problems of aphasia, and advances that have been made are in no little measure due to his labours, the value of which has always been enhanced by his ready appreciation of the work of others and his quickness to combine it with his own in increasing the sum of human knowledge. Pick's original definition of apraxia is couched in the following terms [63]: "Mit dem Ausdruck Apraxie bezeichnet man den nicht durch allgemeine Herabsetzung der psychischen Functionen bedingten Verlust des Verständnisses für den Gebrauch der Dinge." As has already been hinted, and will now be seen, Pick looked at apraxia rather from the sensory side, but he was one of the first to demonstrate the possibility of the occurrence of apraxia apart from any loss of kinæsthetic or other sensory images and memories. The persistence of certain impressions may become a fertile source of error in the execution of complex movements; a patient may recognize an object and use it correctly, but be unable to prevent himself from repeating this act when a totally different object is presented to him. He may use a spoon properly, but repeat the action of feeding himself with the next thing he is shown, which may, for instance, be a corkscrew. This phenomenon, to which Neisser [59] gave the name of "perseveration" (*perseveratorische Reaktion*), this inertia or fixation of idea (*Festhaften, Haftenbleiben*), is curiously frequent in the determination of apraxia. Pick emphasized its importance, and gave the resulting defect the name of "pseudo-apraxia," and in later publications he has continued this usage. In his "Studien über motorische Apraxie" [68] (1905) many interesting facts are recorded and their interpretation discussed. Attention is devoted to the not uncommon occurrence of odd, inapposite movements (*vertrakte Bewegungen*) of face or other musculatures as an accompaniment of apraxic phenomena.[1] They are not of the nature of ordinary associated movements, and are distinguished as parakinesia, or parakinetic movements. An excellent illustrative case, in which true apraxia also was present, has been reported by de Buck [11]. Pick also employs the term "parapraxia," by which is meant the condition where the patient has a normal idea of the intended act, but instead of accomplishing the desired movement he finds himself making an entirely unintended and wrong, though also purposive, movement (*Bewegungsverwechselung*). Pick has devoted some attention to this variety. We have already noted that Liepmann's ideational form is called by Pick ideomotor apraxia.

Since Liepmann's conscientious and illuminating work on the subject, various observers have materially aided in supplying further clinical, pathological, and theoretical data for consideration. The names of Kleist [31], Marcuse [54], Hartmann [19], von Monakow [57], Bonhoeffer [8], Herzog [24], Lewandowsky [39], Maas [53], Abraham [2], Stransky [76], Knapp [33], Nicolauer [60], and Heilbronner [22] may be mentioned. The last named in particular has enriched the study of apraxia with much original observation. He suggests the following classification:—

(1) Cortical apraxia (cortical motor asymboly).—This form is characterized by impairment of the specific functions (*Eigenleistungen*) of the sensomotorium and by the preponderance of parakinetic movements in the execution of any muscular act, or series of acts. It corresponds to Meynert's motor asymboly and Nothnagel's *Seelenlähmung*.

(2) Transcortical apraxia (transcortical motor asymboly).—In this variety the specific functions of the sensomotorium are intact, while voluntary movement-complexes are defective, and in their place we find the inapposite movements already referred to as parakinesis. To these has been applied the term "paramimia" (Liepmann). Parapraxic movements (*Bewegungsverwechselungen*) also occur. Liepmann's case belongs to this category.

(3) Conduction apraxia (*Leitungsapraxie*).—Here we find highly variable defects and perversions of acquired familiar movements and acts, chiefly through the tendency to inertia of idea; there is practically no parakinesis, and the functions of the sensomotorium are normal. Most of the hitherto recorded cases will come under this last group.

(4) Agnosia, with its various subdivisions as previously described. Many errors in movement are secondary to some form of agnosia.

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[1] Dupré [12] mentions the occurrence of these movements in general paralysis, and, without referring to apraxia at all, bestows on them the unnecessary name of "parectropia."

Types (1) and (2) may be unilateral, and may be combined. Types (2) and (3) are often closely allied, while type (3) is usually coexistent with some defect of type (4).

It may appear from this sketch of the subject that unanimity of opinion is still unattained, and that the differences in detail are too great to be surmounted. We see, of course, how the meaning of the word apraxia has changed, but in view of its etymology we can have no hesitation in according our support to the contention of Liepmann that the word should be reserved for a defect on the motor side of the sensori-psycho-motor arc, and on the motor side alone. No good purpose can be served by the adoption of the phrase sensory apraxia, when agnosia is shorter and more accurate, unless the statement is specifically made that what is meant is apraxia of sensory (*i.e.*, of agnostic) origin. For this reason I propose the term, and shall hereinafter speak of, "agnostic apraxia," *i.e.*, apraxia secondary to agnosia.

Further, we may remark that exception is taken by Liepmann [47] to the use of the expression "parapraxia." It is to be observed that apraxia and paralysis are not identical; the person who cannot make purposive movements with his arm because it is paralysed is not apraxic but akinetic. Now, the parapraxic patient makes one movement where he obviously intends to make another; he waves his finger in the air when he means to put it on his nose; he has failed to execute this particular subjectively purposive movement; but according to the definition the apraxic patient, too, cannot make subjectively purposive movements; hence apraxia and parapraxia are really the same. We can scarcely say, therefore, that parapraxia and apraxia are related as are paraphasia and aphasia. But this question may be left aside for the present.

In spite of differences and hiatuses, however, from the material now available certain facts stand out which warrant us in attempting something more than a merely tentative definition and classification, and once this stage is reached in the prosecution of any subject we know from the experience of other times and other topics that subsequent accumulation of clinical data will not confuse, but will serve to elucidate.

DEFINITION AND CLASSIFICATION.

Apraxia may briefly be defined as follows:—

INABILITY TO PERFORM CERTAIN SUBJECTIVELY PURPOSIVE MOVEMENTS OR MOVEMENT-COMPLEXES, WITH CONSERVATION OF MOTILITY, OF SENSATION, AND OF COORDINATION.

Imperfect motility and inaccuracy of movement may be of manifold origin. The place which apraxia takes in the series may be profitably demonstrated if we set down in order, from the afferent to the efferent side of the cortex, the various defects of cerebral function that may occur to impair movement. In this process we shall begin with sensory paralysis, and pass over the sensori-psycho-motor arc to motor paralysis.

(1) *Cortical blindness, cortical deafness, cortical sensory paralysis:* Loss of visual, auditory, and cutaneous ingoing sensory impressions.

(2) *Cerebral ataxia* (*Rindenataxie*) *:* Loss of afferent kinæsthetic impressions, resulting in erroneous estimation of range, power, &c., of movement.

(3) *Mind-palsy* (*Seelenlähmung*) *:* Incapacity for movement from loss of kinæsthetic images and memories for complex movements.

(4) *Agnosia, mind-blindness, mind-deafness, &c.:* Conservation of sensation, but failure of recognition; loss of sensory memory pictures; interruption of connections between sensation and memory.

(5) *Ideational agnosia:* Loss of the spatial associations and interconnections that build up the idea of an object from its component ideas.

(6) *Ideational apraxia:* Defective synthesis of the ideational components of a movement-complex; defective psychical "sketch" of movements or acts.

(7) *Motor apraxia:* Intactness of the cortico-muscular apparatus, but inability to translate a normally produced idea of a movement into the corresponding movement-form.

(8) *Motor paresis or paralysis.*

Perseveration as a cause of disturbance of action is best included under (6).

CLINICAL.

The materials for the scientific study of apraxia are increasing; already the facts are almost more than can be easily assimilated, but, on the other hand, various hypotheses have been advanced which have not as yet received adequate support, and workers in this field must continue to gather and sift ere finality can be reached. I do not propose to do more than illustrate the different types of apraxia by cases which are unequivocal in their bearing, and which are sufficiently clear instances of the particular variety under discussion. I have myself observed and examined not a few patients who present the phenomena that concern us here, and I should like to take this opportunity of acknowledging my great indebtedness to various members of the National Hospital staff for permission to refer to cases under their care. In addition, my thanks are due to Dr. W. H. B. Stoddart, of Bethlem Royal Hospital, for clinical material generously afforded me, and for his kindness in allowing me to examine patients independently.

(1) *Instances of Motor Apraxia.*

It has already been remarked that many patients with motor aphasia are unable to make certain movements though the muscles concerned are not paralysed. Such patients often fail to put out the tongue on request. One patient[1] with severe motor aphasia was urged in vain to protrude her tongue, but on being told to put a stamp on a letter addressed to her husband she put out her tongue to lick the stamp. Frequently these patients are unable to cough voluntarily, are unable to take a deep breath, are unable to sigh when asked to do so. I have observed that not uncommonly they cannot make the movement of swallowing, though they have not the slightest dysphagia when they are actually eating. An aphasic patient[2] was unable to sniff voluntarily, but when he was offered a flower he sniffed it at once. These are examples of bilateral apraxia, which is common in the muscles of the head, neck, face, and trunk. One of Lewandowsky's [38] patients, with cerebral diplegia, was unable to close the eyes voluntarily, though the lids followed the eyes downwards and were closed during sleep. Some hemiplegic patients seem to be unable to close the eyes properly on request. Others cannot make a given grimace.

Unilateral apraxia in the non-paralysed arm is not infrequent in cases of hemiplegia with or without motor aphasia; that is, left-sided apraxia occurs in a left hemisphere lesion. The significance of this we shall see again. The following is an abridged note of the examination of such a case[3] (the symbol + means that the patient's response was correct):—

Shut your eyes	+
Put out your tongue	+, but shut eyes at same time.
Show your teeth	+
Put your left hand on your head ..	Put left hand on chin.
Look astonished	Put left hand on chin.

[1] A. N., under Dr. Beevor.
[2] J. W., under Dr. Ormerod.
[3] W. P., under Dr. Ferrier.

Smile	Made hissing noise through teeth.
Look angry	More or less correct.
Put your left hand on your right ear ...	Put left hand at once into left eye.
Put your left forefinger on your nose ...	Caught hold of nose with finger and thumb of left hand.
Cough	Took a deep inspiration and blew through teeth several times.
Take a deep breath	Made a hissing noise through teeth twice.
Close your left hand	+
Open your left hand	+
Make movement of cutting with scissors	Indefinite movements of left forefinger and thumb.
Make movement of striking a match ...	Stuck forefinger and thumb vertically on to bed.
Make movement of counting pennies out of your hand	Touched thumb and tip of each finger in turn.
Turn the handle of a barrel-organ ...	+

With actual objects in his left hand the patient succeeded a little better, but the motor apraxia was none the less obvious.

Given a buttonhook	Fumbled with the object aimlessly.
(Was shown how to use a button-hook, and then)	
Given a papercutter	Made the movement of buttoning.
Given a pencil	Used correctly.
Given a brush	+
Given a comb	+
Given an anchor	Combed his hair with it, then moved it to and fro on the bed-clothes and said "Whoa!"

This brief excerpt contains highly characteristic examples of bilateral and unilateral motor apraxia, with perseveration, inapposite movements (*vertrakte Bewegungen*), and so-called parapraxia. Be it observed that there was neither word-deafness nor object- and mind-blindness, *i.e.*, the apraxia was not of agnostic origin. When asked, the patient indicated clearly enough that he knew what the objects were for; but when he came to translate his ideas into action he made either an unintelligible or else an entirely wrong movement (so-called parapraxia). The phenomenon of perseveration is well exemplified, and suggests a somewhat wider impairment of cerebral function.

A patient whom I saw at Bethlem was handed a cigarette-holder, consisting of quill and amber piece, and a cigarette. He recognized the objects, and said they were for smoking, but when he was asked to put them together, he tried to put the cigarette into the quill, then into the wrong end of the amber piece, and finally, after further efforts, he laid the objects down. Pick [68] tells of a patient who was given a five-crown piece into his right hand. The sleeve of his shirt was rather long, and came over his wrist so as to hide the money. He made the most futile attempts to bring out the coin, ignoring his other hand, and then, with a long-drawn sigh, put the object aside. Another case was given a candle and a match-box: she took out a match, made rubbing movements with it in the air above the candle, then reinserted it in the box. On being urged to light the candle, she took a lighted match which was offered her, held it near the wick of the candle, then blew it out.

Liepmann's [40] [47] case of unilateral motor apraxia has become celebrated, and justly so, for the completeness and instructiveness of the examination. His patient was a man aged 48, who contracted syphilis twenty years before, and showed indications of widespread arterial degeneration. He had a series of attacks which left him in a state of what was characterized as "almost absolute imbecility." The diagnosis was apoplexy, mixed aphasia, and dementia, and he was sent to an asylum. When he came under the care of Liepmann there was no paralysis, except slight weakness of the left side of the face. (At a later stage the paralysis extended considerably—see below.) Hemianopia was absent, but there was some diminution of the knowledge of the sense of position and of passive movement on the right side of the body, diminution of sensibility to pain, and impairment of the faculty of recognizing objects by touch alone. He suffered also from motor aphasia, but there was no trace of word-deafness. It was soon found that he had bilateral motor apraxia for face and neck and head movements, and unilateral apraxia of the right arm and right leg. Asked to put his right forefinger on his nose, he said "yes," and with his stretched forefinger executed wide circling movements in the air. He made the correct movement at once with his left hand. Asked to close his right hand into a fist, he performed various absurd movements of his arm and body, but attained the required goal at once with his left hand. When asked to give the examiner a certain object with his right hand, he frequently picked up the wrong thing, and, still holding it in his hand, used the left to take up the required object and present it to the physician. He was desired to brush the examiner's coat: accordingly, he took the lower corner of it correctly with his left hand and held it out, while with his right he picked up the brush, but made rhythmical movements with the latter in the air above his right ear. He was asked to pour water out of a carafe into a tumbler: his left hand grasped the handle of the carafe to pour out the water, but his right hand seized the empty glass and brought it at the same time in the direction of his mouth. At a telephone he took the left receiver with his left hand and applied it to his left ear; with his right hand he turned the handle first one way and then another, then took the right hand receiver and put it on his forehead, making nodding and puffing movements the while; then he held the receiver before him and gazed into it, finally carrying it to his mouth and then behind his ear. The movements of the right hand in this last example may be cited to illustrate so-called parapraxia.

Enough has been quoted to exemplify the inability of the patient with motor apraxia, in spite of the absence of any perceptual defect, to translate his ideas into the corresponding action; de Buck's [11] patient was asked to lift her right arm, but after crossing it over her body, putting her hand in her left axilla, and making various energetic but hopeless efforts, she said plaintively, "Je comprends bien ce que vous voulez, mais je ne parviens pas à le faire," and there lies the whole situation in a nutshell.

(2) *Instances of Ideational (Ideomotor) Apraxia.*

One or two of the examples that have already been given illustrate rather more than a purely motor or psychomotor defect. Without entering on detailed analyses of each I shall now give a few instances of the apraxia that results from interruption of intrapsychical function.

One of Pick's [68] patients was handed a toothbrush, which he recognized, but when asked to use it he began to brush his beard with it clumsily. This is an excellent instance of the so-called "associative apraxia" of Bonhoeffer [8]. Evidently the concepts "toothbrush" and "beard brush" were confused, with a consequent confusion of movement. The patient "went off the rails" (*Entgleisung*) in the ideational part of the act. On another occasion a pistol was offered him, which he said was a revolver; to show how to shoot he grasped the barrel, blinked, and put the muzzle against his right eye. Liepmann [43] takes this example to indicate the same associative apraxia, inasmuch as the object had not called up the special idea of a pistol, but the general one of a firearm (which suggests some slight agnosia and shows the close relation of agnosia to this form of apraxia); and the idea of a gun controlled the subsequent movement. When the patient was supplied with a cigar and a matchbox he opened the latter, stuck the cigar in, and tried to shut the box, apparently as though it were a cigar-cutter. Then taking the cigar out he rubbed it on the side of the box as though to light a match. In this movement-complex, the components of the main idea of action, viz., to light a cigar, neither followed in the right order nor were directed to the proper objects—a fine illustration of ideational apraxia. On yet one other occasion, when all the necessaries for smoking were laid before him, he took the matchbox and, putting it between his teeth, tried to smoke it. Here the ideational components of the complex are omitted. No sooner is the action begun than the movement that should come last is carried out. This is a good example of what is called the *Kurzschluss-Reaktion* (short-circuit reaction).

In another case [68] the patient recognized a shoebrush, and picked it up to brush his boots, but rubbed it over an excoriated area of his skin instead. A sensory impression from the skin interrupted the "draft" of the action and diverted the patient's "intention."

In this connection I may refer to a patient with arterio-sclerosis at Bethlem. I invited him to make the movements of counting out money with his right hand, which he effected very badly. Accordingly I made the movements myself for him to imitate, and he began to do them correctly enough; to aid him, as I thought, I told him to count into my hand, and put it out for him to count the (imaginary) money into, when he at once grasped it and shook hands with a smile! One may say here, too, that the ideational plan of action was interrupted by impressions from other sensory centres, and the incident is a further illustration of the influence of perceptual defects in the production of ideational apraxia. It is interesting, also, as showing the persistence of those movements which have the greatest number of associations. The associations which the sight of my hand awakened were more potent for the movement of shaking hands than for the movement of counting out money.

Where a greater degree of cortical functional disintegration exists, as in many cases of dementia, from whatever cause, apraxic phenomena may appear in increased complexity. One reason for this is the frequent concurrent development of agnosia in some or other form, and this agnosia may be profound. Mental troubles of a general nature, such as amnesia, inattention, incapacity for retaining impressions, lack of initiative, militate against eupraxia, apart from impairment of the specific sensori-psycho-motor paths. Marcuse [54] has described apraxia in senile dementia; Abraham [1] and Lewandowsky [37] in general paralysis; Stransky [76] in senile cerebral atrophy; Bonhoeffer [7] in the delirium of alcoholism; Pick [66] in post-epileptic stuporose conditions, &c. I shall have occasion to refer to some of these cases immediately apropos of the determining factors in the production of apraxia. Because a patient is insane, demented, delirious, any apraxia which he may show is none the less apraxia; it is none the less deserving of study. The more we can reduce psychical disturbance to its component elements, and the better we can estimate the action of known pathological processes, the less elusive and mysterious will that disturbance become.

DETERMINING FACTORS IN THE PRODUCTION OF APRAXIA.

(1) *Agnosia.*

For various reasons it is not desirable to say much in regard to the position of agnosia as a factor in the production of apraxia. To enter into the question at all adequately would prolong this paper unduly. The different forms of agnosia have already been sketched, and a mere glance at their variety will suffice to render obvious the manifold possibilities of agnostic apraxia. There are many ways in which recognition of an object may be at fault. The idea of, say, a tree is a complex of simple ideas (twigs, leaves, trunk, roots, &c.). Each of these is in itself complex, for we have, in the first place, the idea of the spatial form and relations of each part, and, secondly, a sum of qualitative subsidiary ideas, viz., visual, tactile, olfactory, &c., for each part. In the process of recognition of an object, the two series of partial ideas are linked together. Each idea of an object is a complex of component spatial ideas and of component tactile, visual, and other qualitative ideas. If there is any interruption, by pathological processes, between the qualitative (visual, tactile, &c.) elements in one or more of the component ideas that go to form the idea-complex, then we have a disturbance of recognition which is known as (sensory) agnosia. There are as many varieties of this disturbance as there are senses. Clinically we have preservation of primary sense perception, with inability to awaken images through a particular sense; from any of the other senses the idea can be awakened. A patient may have visual agnosia, but not tactile agnosia. Meanwhile, the association of the spatial component ideas in the idea-complex is not interfered with. But a lesion may cause dissolution of the associations between the spatial component ideas of the complex idea; there is a defect in the building up of the idea from its constituent ideas which does not depend on the quality of the original sense impressions; *i.e.*, whether the object be seen, or felt, or heard, is a matter of indifference. This disturbance of recognition is ideational agnosia.

Now, this brief psychological sketch will help us to realize the complexity of the process of identification by any one of the senses, and the corresponding complexity of imperception. Mistakes on the sensory side are exteriorized into errors of movement, hence the multiplicity of apraxic phenomena of agnostic or perceptual origin. What has been said of ideas of objects is true of ideas of movement. The latter may be divided into the spatial components of each partial idea in the complete idea and the qualitative (visual, kinæsthetic, &c.) components of each partial idea. Ideational defects entail apraxia here also.

There are many instances of apraxia of agnostic derivation in the literature. As a matter of fact, much more attention has hitherto been devoted by observers (with the conspicuous exception of Liepmann) to the study of the psycho-sensory side than of the psycho-motor side of impaired mentation. Nearly all the early cases of apraxia were cases of agnostic apraxia, of which many examples might be given. A patient of Laquer's [35] used a comb instead of soap to wash her face with. She bit into the soap, but recognized it by its taste. Agnostic patients often take hold of objects in the wrong way. The reader will find instructive the apraxia of Pick's [64] patient, who laboured under the disadvantages of auditory agnosia, visual agnosia, partial tactile agnosia, olfactory agnosia, and gustatory agnosia.

One of the Bethlem patients already referred to exemplified a highly complex type of combined agnostic and ideational apraxia. I handed him a match—he was a great smoker—and asked him what it was. He said at once, "Oh, that's a pen." I agreed, and requested him to demonstrate its use. He replied, "Why, you clean your teeth with it," and, at the same time, he took it in his right hand and cleaned his finger-nails with it.

In this admirably suggestive incident the patient's visual agnosia was responsible for his saying that the match was a pen. In all probability he meant a pen nib. So far, however, from using the match as a pen, he was deflected from that idea by the association of a pen nib with something pointed, so that a tooth-pick rose in idea before him; again association interrupted his ideational sketch, and at the same moment as he said "*teeth*" he carefully manicured his *nails*. It is another instance of associative apraxia.

(2) *Perseveration.*

A factor in the determination of apraxia, noteworthy both for its frequency and its compelling character, is perseveration. Perseveration, according to Pick [66], is the result of feeble associations. The individual is absorbed by one idea to the exclusion of others which the examination ought to awaken. Such perseveration is of ideational origin, but the question is a difficult one to answer whether it is due to abnormally long persistence of the first idea ("ideational inertia" is the term suggested by Dr. Stoddart) or to some hindrance in the presentation of subsequent ideas. Liepmann [43] has enlarged on the importance of recognizing perseveration of psycho-motor origin. A motor innervation which has already been carried into effect repeats itself whenever the patient endeavours or intends to make a different innervation. There is neither persistence of innervation nor spontaneous innervation, but a repetition of the already executed one when (and only when) he intends to make a new movement. Liepmann distinguishes this variety as "clonic perseveration."

Pick's "Studien" contains many examples. One of his patients blew out a candle, and then blew on all objects subsequently presented to him. There is often a characteristic perseveration in the parapraxia of motor aphasics and other hemiplegics on the non-paralysed side.

In the selection already made from the examination of the case W. P., there are instances of the same *Haftenbleiben.* He was given a small comb, which he used correctly, then a toy anchor was put into his hand, and he combed his hair with it as well. In the same way he repeated with a paper-cutter the movements of buttoning with a buttonhook.

To another[1] of the patients who has come under my own observation—a case of generalized cerebral arteriosclerosis—I handed a match, and asked him if he knew what it was; he said it was a match, and at once made the correct movement for striking it. I then gave him a pencil; he said, "That's a piece of pencil," and when asked what it was for, he continued, "For writing, of course." "How do you use it?" "Oh, you strike it like this," he said, and repeated the identical movement he had made a minute before with the match.

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[1] S. C., under Dr. Risien Russell.

Another patient[1] recognized a small magnifying glass which I gave him, and, saying, "That's a very pretty thing," put it to his eye correctly. He next received a Yale lock key, which he did not know. On being told what it was, and in spite of the fact that he repeated "key," when asked to use it he put it to his eye and said, "That's a very pretty thing."

Perseveration of speech and perseveration of writing are of much interest. A patient under the care of Abraham [1] who had been asked to put out his tongue was then told to write down something, when he at once wrote "tongue," and continued to do so in answer to other questions. One of the Bethlem patients, suffering from early arteriopathic dementia, was given a buttonhook, and said, "Oh yes, that's for boots." He made a poor attempt to indicate the method of using it, and was handed a knife. He looked at it a minute or two, then said, "That's for boots." He could not get any further with the object, so I gave him a matchbox, which he fumbled with rather helplessly, and when I opened it for him he said, "I think that's for boots."

It may be noted, in passing, how very different perseveration of speech is from the "recurring utterances" described by Hughlings Jackson, and from the verbigeration of certain forms of insanity.

(3) *Absence of Initiative.*

Connected with perseveration is another psychical defect of some significance, called, in Germany, *Willenlosigkeit;* we might coin a word "will-lessness," but "defect of volition" or "absence of initiative" is sufficiently accurate. Not infrequently apraxic patients exhibit a curious lack of spontaneity, an unwillingness or inability to do things for themselves, which is not without bearing on the development of apraxic phenomena. In one or two of the recorded cases this lack of initiative has been remarked, and Pick [68] has devoted some attention to it. One of his patients had a burnt match in his hand and seemed unable either to let it go or to throw it away. Liepmann's [40] patient complained that sometimes he could not relinquish his grasp of an object in his left hand. Pick's view is that there is momentary cessation of spontaneity, momentary "will-lessness." Liepmann thinks there there is persistence of innervation, a condition which he describes [43] as "tonic perseveration," as opposed to the "clonic perseveration" of the previous paragraph. Other instances may be cited with advantage. One of Bonhoeffer's [7] patients, who showed agnostic apraxia, associative apraxia, perseveration, &c., would allow his legs to rest wherever they were passively put by anyone. He rarely moved them voluntarily. Bonhoeffer uses the term pseudo-flexibilitas cerea for the condition, which is obviously distinct from true flexibilitas cerea. Absence of spontaneity is not infrequently associated with agnosia. The remark of Wernicke has already been quoted, that patients with asymboly cannot turn new sense-impressions to account, which is the mainspring of action. Rabus [71] agrees that such patients must appear stuporose, since the ideas which constitute their mental life are in great part gone, and impressions from without fail to elicit any response. Bonhoeffer [7] has noted the remarkable fact that patients in the delirium of alcoholism may, on request, move their hands and arms, put out the tongue, &c., but they will not stand up spontaneously, or turn about from one position to another, or draw their feet or legs up. A general paralytic under the care of Lewandowsky [37] showed extraordinary inability to do anything for himself: he could not sit up, rise from his seat, walk forwards or backwards, unless he was made to do so, when the movements were accomplished normally enough. In this patient's case there was a slight paresis of the left arm, yet with it only three movements were ever executed, viz., one to the back of the ear, one to the mouth, and one a rubbing movement of the hand on the head. One of Pick's [68] patients was asked to go to the table and eat something; he went forward and put his face into a milk-jug which was standing on the table, and remained so, almost motionless, for several minutes. The interpretation of these interesting facts, where action seems to come to a standstill, is, as already hinted, debatable. Pick inclines to the view that the idea which impels an act is lost with the commencement of the act, a form of ideational inertia. He quotes from James [30]: "A certain intensity of the consciousness is required for its impulsiveness to be effective in a complete degree. There is an inertia in all motor processes as in all other things. In certain individuals and at certain times (disease, fatigue), the inertia is unusually great, and we may then have ideas of action which produce no visible act." Of course, certain instances of this condition may be due to absolute lack of attention or to the fleeting character of afferent impressions (see also below).

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[1] At Bethlem.

There is a case[1] of left hemiplegia in the National Hospital at present which presents certain features of unusual interest for our subject. It is a case of mitral stenosis with an ordinary embolic lesion of considerable extent in the right cerebral hemisphere. The clinical picture is one of complete flaccid paralysis of the left arm and leg; the left face is also affected, but to a much less degree. On examining the patient one is at once struck with her immobility and lack of spontaneity. She rarely speaks unless spoken to; she still more rarely makes any voluntary movement of her non-paralysed right limbs. When requested, however, she can perform any movement with her right arm in an eupraxic way, and there is no agraphia. Her face is more or less "fixed" in an expression suggesting anxiety; her eyebrows are symmetrically elevated, and her eyes look straight in front of her. This expression never varies. She is quite incapable of making any grimace, of smiling, of laughing; when asked to try, her reply is "I can't." She is incapable of closing her eyes on request, or, rather, of sustaining the contraction, for she will close them momentarily, opening them again without the slightest pause. She is unable to look voluntarily to the right or the left, and it is only with difficulty that she can be tempted to gaze in either of these directions, by the stimulus of a sound or otherwise. Yet there is no paralysis of conjugate deviation at all. She can protrude her tongue, can show her teeth, bite, &c., well enough. Her voice, since the stroke, has been peculiarly monotonous and rather shrill: she is incapable of modulating it. There is a fixity of tone more or less in keeping with the fixity of her facial expression, but I have the authority of Sir Felix Semon for the statement that the larynx is normal. She is incapable of making the movements of swallowing, though with food in her mouth she swallows well, if slowly; she cannot cough, or sigh, or yawn voluntarily.

Here, then, is a left hemiplegic patient with bilateral apraxia of face and throat musculature for certain movements, and with pronounced defect of volition or of initiative. Such a case may be considered in two ways. There may be actual paralysis of certain movements. But, as has been indicated, there are in this case few, if any, movements that are really lost. On the other hand, there may be inability volitionally to awake or innervate certain movements or movement-complexes, and thus apraxia may be determined. The kinæsthetic ideas of these movements are intact, but the patient cannot voluntarily revive them. Such seems to be the case in this instance.

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[1] A. P., under Dr. Risien Russell.

Those who have had occasion to study astereognostic patients must have been struck with the way in which they seem to have difficulty in handling the object properly, though there is no trace of motor paralysis.[1] That this deficient handling and turning to and fro of the object do not necessarily depend on loss of sensation—and therefore cannot be likened to the deficient motility of the apæsthetic limb—is clear from their occurrence where there is no discoverable diminution of cutaneous or even of deep sensation.

A patient[2] recently seen, from whose right superior parietal lobule a bullet was removed, exhibited astereognosis in the left hand for several days after the operation. No loss of cutaneous sensation existed, but there was occasional (not constant) erroneous estimation of passive movements of the fingers, particularly of flexor movements. When he was tested with Cattell's algometer no alteration in deep pressure pain was found. He betrayed no motor paralysis whatsoever, but when an object was put into his left hand, his eyes being closed, he grasped it firmly with his whole hand, and showed no spontaneity in fingering it or handling it. He never made any effort to manipulate it at all: even with eyes open there was little initiative in fingering it. One may very well question whether the astereognosis was not secondary to the akinesia of the hand and fingers, a "pseudo-astereognosis." It is possible that the condition was analogous to Nothnagel's *Seelenlähmung*, and due to failure of kinæsthetic memories and impressions, but the patient could on request make at least some normal movements with his left fingers and hand when his eyes were shut. One is rather inclined to class the case as a dyspraxia secondary to perseveration or absence of initiative—a volitional defect which may in some way be due to absence of certain normal afferent stimuli, and the local incidence and transitory nature are of great interest.

I have also seen a case[3] of right cerebral tumour with progressive left hemiplegia, where the patient is unable to relax his grasp of an object for many seconds, even though he makes strong associated movements with his right hand. He shows a similar inability to relax other muscles of his left arm. The left leg also is somewhat affected. Such a condition of defective inhibition of protagonists—for it is apparently not a sequel to defective innervation of antagonists—may be due to impairment of the specific functions of the sensomotorium, and not to a pyschomotor abnormality. There is considerable reason to believe, however, that it points to impairment of function of the corpus callosum. In a footnote Liepmann [43] says that van Vleuten has shown him a case of cerebral tumour presenting the same feature—probably the same as van Vleuten's recent case [78]. Further reference will be made to this "tonic perseveration" in a subsequent paragraph.

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[1] This condition has been noticed by Brissaud and Marie.

[2] H. G., under Dr. Risien Russell and Sir Victor Horsley.

[3] A. J., under Sir William Gowers and Sir Victor Horsley. From this patient Sir Victor Horsley has since removed by operation a large endothelioma of the right frontal lobe, which was situated close to the mesial plane and spread backward under the sensomotorium in its upper part.

(4) *Inattention, Incapacity for Retaining Impressions.*

Other general, and important, determining factors of apraxia are amnesia, inattention, and defective capacity for retaining recent impressions (*Merkfähigkeitsstörung*). The *rôle* played by these can never be negligible, but, on the other hand, we must beware of contentedly attributing everything to their action. Inattention is usually obvious, and its influence therefore ought to be excluded with relative ease. Jackson's patient [25], who could not be made to look in any particular direction, although he seemed on the alert to act, and was all the time doing something with his muscles, can scarcely be accused of inattention. A patient of Pick's [68] applied a match to a stick of sealing wax so that the wax dripped off, but when handed a seal he pressed it on the stick and not on the molten wax. Pick thinks this incident indicative of inattention on the part of the patient, and of inattention alone. Marcuse's [54] case of senile dementia exhibited profound disturbance of memory. Her impressions were fleeting in the literal sense of the word. When told to pour water out of a carafe into a glass and replace the stopper she came to a standstill in a second or two, and asked what she had to do. We may, if we choose, describe the condition, with Marcuse, as one of "amnesic apraxia," but the phrase is otiose. It appeared that those movements were best carried out which awakened the greatest number of associations, and therefore complexity of movement was of secondary importance. The patient had difficulty in bringing her finger-tips together on request, though she used a knife and fork well; she could peel potatoes, but could not make the military salute. Her forgetfulness was such that in a few seconds she could no longer repeat what had been said to her; the repetition of three numbers was nearly always impossible. Bonhoeffer's [8] patient suffered from a similar incapacity for retaining impressions; visual, auditory, tactile, kinæsthetic impressions alike he was powerless to recall in about ten or fifteen seconds. He could not bring the immediate past and the immediate present together. It is of interest to note which are the movements that are least likely to suffer in a case of apraxia. Dr. Jackson has held that the most automatic movements are the last to be affected, but it seems to me Marcuse furnishes weighty evidence in support of the view that those movements are best preserved which have the greatest number of associations—which is not quite the same thing. I have seen a male patient[1] with cerebral abscess in the left centrum ovale (posterior part) who failed to make any recognizable and suitable movement with his non-paralysed left hand when a pair of scissors, a pencil, a knife, a key, were in turn given him. But no sooner was a pipe handed him, with the bowl towards him, than he quickly reversed it, put the mouthpiece in his mouth, and went through the apposite pantomime of smoking. The movement of cutting with a pair of scissors is surely automatic enough, but the associations of the movement, for a man at least, are not far reaching, whereas those awakened by the sight of a pipe are more potent. It has been noticed by Heilbronner [22] that in testing female apraxic patients he has never once had occasion to remark that they made the movements of smoking in mistake for some other.

One may, I think, include under this section those cases where the patient makes mistakes in eating or in dressing. One of my cases,[2] already referred to, spent an unconscionable time in dressing and in eating his breakfast. It was observed, on several occasions, by the Sister of the ward that he took a few mouthfuls of porridge, then had a drink of tea and a bite or two of bread, then sometimes he treated himself to a spoonful (or considerably more) of marmalade by itself, then back again he went to his porridge, then perhaps he would address himself to his egg, and so on. It has happened that after finishing the other parts of his breakfast he had still porridge to take. Pick [65] had a patient who used to keep his food an interminable time in his mouth, and who never seemed to "get any further" with his meals.

In not a few of the recorded cases inability to dress properly has been observed. Laquer's [35] patient put on his stockings after he had put on his shoes. In Jackson's [27] case of imperception the patient put her things on wrong side before. The patient[3] just referred to made mistakes of a similar nature. He got into difficulties with his shirt and his waistcoat; he put his shirt over his bed jacket, and his waistcoat over his coat. It seems clear that in these examples—which are only a few out of many—the defect is of an ideational type, partly dependent upon impaired recognition, but more directly the sequel of inattention and incapacity for retaining impressions.

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[1] S. M., under Dr. Aldren Turner and Mr. Ballance.
[2] S. C., under Dr. Risien Russell.
[3] S. C.

There is a curious feature in some cases of apraxia which deserves to be mentioned. They evince indifference to their mistakes and show a somewhat surprising inability to profit by these mistakes. Even where the correct movement is executed before the patient's eyes, even though he expresses his knowledge of what is required, he proceeds to repeat the mistake unconcernedly. The explanation of this *Nichtkorrektur* is not perhaps obvious. It may lie in the fact that the attention and capacity for retaining impressions of the apraxic patient are at fault. In some cases, no doubt, such is the most satisfactory view to adopt. On the other hand, one is struck by the rather unreasoning assurance of some apraxics that the movement which they have just executed is the correct one. A patient[1] already referred to, when asked to put his forefinger on his chin, put it on the top of his head instantaneously, with a smile as of satisfaction, and repeated the mistake a moment later, though he was shown what to do. When told to put his left hand on his right ear, he put his left forefinger into his left eye, without a moment's deliberation, and when asked if he had done what was asked, he nodded in affirmation. Thus a certain absence of deliberation may very fairly be held responsible for the errors, an absence of deliberation not unlike that which occurs in the "short-circuit reaction" (*Kurzschlussreaktion.*) There can be little doubt that knowledge of one's own state of mental impairment, so commonly met with in aphasics, is much less frequent in cases of apraxia. Apraxics do not seem to learn; they do not, as a rule, appear distressed at their imperfections. This point is also alluded to by Heilbronner [22].

By the aid of Wernicke's scheme of the reflex psycho-physical arc concerned in the translation of a sensory impression into an act we may summarize what we have learned of the factors in the production of apraxia.

Let us take the simple instance (Kleist [31]) of the sight of a rose suggesting the idea of my picking it and putting it in my buttonhole.

In this scheme s stands for an impression in a sensory projection field—in our instance a visual impression. A is the idea most intimately associated—in our case a rose. Z is the idea of the result of the action suggested by the idea of the rose, the idea of the object to be attained (*Zielvorstellung*, *Erfolgsvorstellung*), which is, to put the rose in my buttonhole. Finally, *m* is the idea of the movement which is to work out the aim- or object-idea; it is the movement-idea (*Bewegungsvorstellung*) of plucking the rose, &c. In accordance with this idea of movement follows the actual innervation of the sensomotorium. *s*—A is the psychosensory, A—Z the intrapsychical, and Z—*m* the psychomotor limb of the reflex arc.

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[1] W. P.

Now, leaving out of account afferent and efferent defects of the lower levels, ataxia and sensory loss on the one hand, with motor paresis or paralysis on the other, we have already seen that dyspraxia or apraxia will result from lesions of the psychosensory path—agnostic apraxia from imperfect identification. We have also seen how elaborate the process of recognition is, how various are the elements in that process, and how a sensory agnosia or an ideational agnosia may arise. Thus the A of the scheme becomes highly intricate, and its influence on the rest of the arc correspondingly manifold.

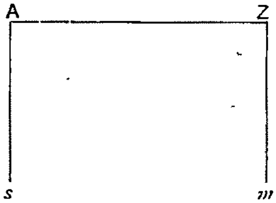

FIG. 1.

The segment A—Z of the arc may be the seat of pathological changes which undermine its function, and consequently cause apraxia. Some reference has already been made to this question. Disturbances of attention, of association, of concentration, exert their influence on A—Z; many of the phenomena of dementia, delirium,[1] &c., will be found, on

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[1] In "Neurological Fragments" (*Lancet*, March 5, 1892) Dr. Hughlings Jackson published a case of agnosia in delirium, with secondary agnostic apraxia, of which he has given me the following illuminating analysis. The case was that of a sack dealer who was delirious during erysipelas. The house surgeon opened a small abscess in one eyelid while the patient was in a strait-jacket. The patient's account of these circumstances was that he had been to a public-house, that the landlord fastened him down with two sacks, and then poked out one eye. Dr. Jackson writes :—

"I send you a diagrammatic exposition of the sack-dealer's delirium distinguishing the two opposite elements of that double symptomatic mental condition into (*a*) the negative element (imperception) and (*b*) the positive or super-positive element.

"(*a*) The negative element, the patient's '*not*-knowings,' his imperceptions (samples of them), are as indicated by the series of five words in the following : (1) *Hospital*, (2) *house* analysis, to have their origin at this point. A few examples have already been quoted, and others will be obtained in the papers of Liepmann [43], Bonhoeffer [7], Heilbronner [22], &c.

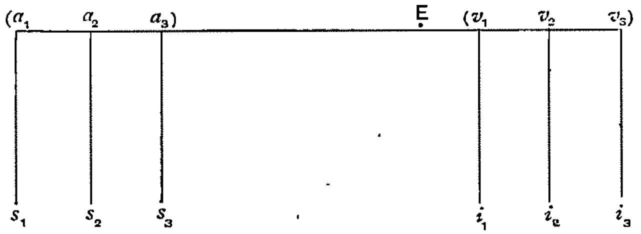

FIG. 2.

I have also indicated the results of defects in Z and Z—m. Interruption of Z—m, *i.e.*, inability to work out or carry into effect a correctly sketched idea of an action, where the sensomotorium is intact, causes pure motor apraxia. But Z is just as complex as we have seen A to be. Let us take Kleist's example once again. If a cigar and matchbox lie before me, and my perception and recognition of these objects are normal, then follows—the intrapsychical path being supposed normal also—the complex aim-idea Z, which consists of the idea of the cigar lit and in my mouth. Z itself is not identical with the idea of the various movements required to effect this purpose, but it is linked with the "working-out idea" (*Verwirklichungsvorstellung*), which is the idea of an elaborate movement-complex, made up of the ideas of a greater or less number of movements, viz., the idea of cutting a cigar, putting it in my mouth, picking up the matchbox, opening it, taking out a match, striking it, lighting the cigar, drawing

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surgeon, (3) *strait-jacket*, (4) *eyelid*, (5) *surgical operation*. These things the patient did not know.

"(*b*) The positive (or super-positive) element, the patient's 'wrong-knowings,' his illusions (samples of them), are indicated by the series of five words in the following: (1) *Public-house*, (2) *landlord*, (3) *two sacks*, (4) *eyeball*, (5) *assault on eye*.

"Although we commonly think of such a case as that of (*b*), that the mental condition is of wrong-knowings, and that these are false perceptions (illusions), that is only how the story is taken by bystanders. This patient's 'illusions' were really *his knowings*, that is to say, they were *true for him*; they were *his* perceptions. Briefly, taking for illustration only (*a*) (1) *hospital*, and (*b*) (1) *public-house*, the patient was, to the observation of bystanders, bodily in the London Hospital; before the onset of his delirium he was mentally there too. But when become delirious, he was *mentally* in a public-house, most likely in one he had often been to. In fact, the præ-delirious man, the man in health, and the delirious man, the patient, were, to a great extent, two different persons. The hospital was part of the præ-delirious man's environment; the public-house was, for a short time at least, part of the delirious man's environment."

in, puffing out. The complexity of each of these ideas is obvious if we think for a moment of the necessary individual movements of fingers, hands, lips, &c. Corresponding to these working-out ideas are the various innervations, and finally the actual movements themselves. Wernicke's scheme is accordingly modified by Kleist in this way:—

E is identical with Z, which is connected with *v*, the working-out idea; and it is, in turn, subdivided into a group of working-out ideas, v_1, v_2, v_3; corresponding to each is an *i*, the sign for the appropriate innervation in the motor region of the cortex. According to Wernicke, *m* represents the kinæsthetic image of the movement as well as the innervation, whereas it is better, with Kleist, to regard the kinæsthetic idea as an integral part of the working-out idea, along with visual and tactile ideas. In this scheme *v*—*i* is the psychomotor path; the connections of E with *v*, and of the various *v*'s with each other, are to be regarded as belonging to the intrapsychical path. Dissociation of the qualitative (sense) components from the spatial components of the various *a*'s produces sensory agnosia; dissociation of the spatial components of the various *a*'s from each other produces ideational agnosia. Separation of the visual and other sense elements from the kinæsthetic element in each of the working-out ideas (v_1, v_2, v_3, &c.) causes motor apraxia; separation of the various working-out ideas from each other explains ideational apraxia. Instances of these have already been described in previous sections. For fuller analysis of this part of the subject and for more comprehensive diagrammatic representation of the sensori-psycho-motor arc, the reader may consult Liepmann or Kleist.

DIAGNOSIS.

After the definitions and analyses and clinical examples that have been selected to illustrate apraxia, a detailed differential diagnosis is a work of superfluity. In the course of this communication we have seen what apraxia is likely to be confounded with, and we have emphasized the necessity of excluding motor or sensory paralysis. Of course, a minor degree of sensory impairment may exist, as was noted in Liepmann's original case, but what has to be considered is whether any such impairment will or will not account for the apraxia. Undoubtedly the greatest difficulty is in some cases of cerebral ataxia (*Rindenataxie*). Cerebral ataxia has not been so carefully studied as spinal ataxia, but it may be remarked that we may have (1) cases where a lesion of the sensory centripetal tracts, involving loss of kinæsthetic impressions, is present, and (2) cases where the lesion causes interruption or loss of kinæsthetic images. A cortical lesion may destroy either the terminations of the sensory tracts conveying kinæsthetic impressions, or the anatomical area subserving the storage of previous kinæsthetic impressions, or both. In this last case the condition which results is no longer pure ataxia, in the sense of impairment of coördination from loss of the controlling influence of afferent impulses, but a combination of ataxia with something else, which is partly of the nature of apraxia or of mind-palsy (*Seelenlähmung*). The apraxic patient who puts his finger in his ear instead of on his chin is not ataxic. But some of the amorphous movements of apraxics are less easy to distinguish. It is of assistance to remember that the ataxic man is unstable in all his ways, whereas the apraxic may perform certain movements without the semblance of ataxia. The simpler the movement, the less the ataxia; the more elaborate the movement, the grosser the ataxia. But the apraxia of the patient bears no constant relation to the complexity of the movement. What he does is often accomplished in such a way as to make us feel that he has not understood the directions, or has forgotten how to perform the movement, or at least cannot awaken the suitable innervation. In ataxia Förster [15] notes that the prime movers are always innervated with promptness, whereas it is a common occurrence in apraxia for these prime movers to fail, while the synergic muscles function conformably to the intended innervation of the others. Afferent impulses determine the "how" of the proposed movement in its finest details, but never the "what."

Of the relation of hysteria to apraxia much might be said. That agnosia and asymboly of functional, *i.e.*, hysterical, origin occur is well recognized, and they entail apraxia in the usual way. As I have more than once hinted at the impossibility of adequately handling the question of agnosia and of other general mental disturbances in this review, I shall not venture further into the interesting field for observation and study which the connection of hysteria with apraxia opens up. Some, at least, of the mental symptoms of hysterical subjects are due to inattention or incapacity for retaining impressions. Some cases show types of perseveration which are identical with those with which we have already dealt. Others exhibit apraxia (or akinesia, rather) from loss of kinæsthetic images. A patient[1] with complete loss of superficial and deep sensation in her left arm performed all ordinary movements with that limb quite readily, on request, so long as her eyes were open, although it was observed that not invariably was her gaze fixed on the part being moved. If her eyes were shut, practically no movement was executed at all, though she maintained that she *thought* she had made the movement. As the arm did not move, there could be no kinæsthetic impressions. If, then, the patient *thought* there was some displacement of the limb, the corresponding kinæsthetic images or memory pictures may have been called up, but may have failed to awaken innervation.

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[1] S. McG., under Dr. Ormerod.

The reader will find much material suggestively handled in a paper by Raecke [72] on the so-called "twilight states" (*Dämmerzustände*) of hysteria.

I should like to take this opportunity of directing attention to certain disturbances of motility which may occur in acute chorea. In an ordinary case of Sydenham's chorea the examiner is usually able to distinguish three types of motor affection: involuntary movements, incoördination of voluntary movement, and muscular asthenia. These three may be present in varying degree, and indeed they may not all be discoverable. But in some cases there is a change which is definitely of a psychomotor nature, and which has not received investigation as far as I am aware. I do not refer to what has been called paralytic chorea [17], where the patient "loses the use of a limb." This is a condition of akinesia, of inaction without paralysis. The limb may become immobile, without any spontaneous movement, and the patient may have recurring attacks of this nature. Recently, however, I have had occasion to observe some cases in which there was distinct perversion of movement, in which a given movement was either not performed or replaced by a wrong one, and this apart from any incoördination. In a case[1] of this kind the following points were noted:—

Put your right hand on the top of your head	+
Put your left hand on the top of your head	Made a sudden movement in the proper direction, but stopped opposite the left ear, and then put her hand on her left ear.

I remonstrated with her and asked whether she had done what was wanted. She replied, "I can't do it."

Put your right forefinger on your nose	+
Put your left forefinger on your nose ...	Made an abrupt movement in the direction of her mouth, stopped opposite her chest and put her hand with the palm down flat on her chest.

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[1] E. D., under Dr. Aldren Turner.

In this instance also the patient said "I can't." Although the movement was initiated properly, she ended by making a wrong movement, in spite of her expressed intention.

Put your right forefinger in your left ear	+
Put your left forefinger in your right ear	At once put her left hand on to her chest, and let it rest there.

I asked if she knew what was wanted, and she answered in the affirmative, but repeated that she could not do it.

The patient was able to open and shut her eyes, put out her tongue, &c., in the usual way. With her left hand she was perfectly able to grasp and relax, she was able to flex and extend at wrist and elbow, and to move her arm at the shoulder. On the whole, the involuntary movements which she exhibited were worse in the left upper extremity than in the right, but such incoördination as was present was practically equal on the two sides.

In the consideration of these phenomena the description of her physical symptoms makes it clear that the former can be attributed neither to incoördination nor to the greater amount of involuntary movement on the left. Are they, then, akinetic in nature? It is true that such muscular asthenia as the patient revealed was possibly of greater incidence on the left side, but it has just been stated that various ordinary simple movements were executed very well by the left arm and hand. The view which commends itself to my mind is that in this case there is a degree of apraxia or parapraxia for certain movements of a reflexive nature, and this parapraxia is unilateral. It is probably transcortical in origin, due to a partial functional isolation of the right sensomotorium. That some at least of the phenomena of chorea are attributable to transcortical disturbance has been recently shown by Kleist [32]. In this connection we do well to remind ourselves that in acute chorea Poynton and Holmes [70] found vascular and nerve-cell changes in every region of the brain and brain-stem.

RELATION OF APRAXIA TO APHASIA.

The study of the relation of apraxia to aphasia, and in particular to agraphia, cannot well be entered on except *in extenso;* we may, however, indicate in a general way the analogies between these disturbances of cerebral function.

In right-handed persons the lesion which produces aphasia in any of its varieties is in the left hemisphere. Similarly, apraxia is very much more frequent in disease of the left hemisphere than of the right in right-handed individuals. Aphasia is cortical, subcortical, or transcortical in origin. Apraxia, as far as we know, is always supracapsular, and may be either cortical, subcortical, or transcortical. The two are not necessarily associated. We may have aphasia without apraxia or apraxia without aphasia.

Speaking generally, we have in Broca's area a centre for the coordination of movements requisite for speech: in this area movements of tongue, throat, palate, larynx, &c., are combined prior to the actual innervation of the cortico-muscular apparatus, which takes place in the sensomotorium proper. There is considerable reason to believe, as we shall see, that there is an analogous "centre" for the coördination of certain movements, or movement-complexes, of the limbs, in the first and second frontal convolutions of the left side, and that movements are here combined ideationally, to be innervated in the sensomotorium. As Broca's area controls bilateral muscles, so the eupraxia "centre" guides the movements of both sides of the body, which must obviously depend on intactness of the corpus callosum.

In motor aphasia we have a form of apraxia, viz., apraxia of the speech musculature. The motor aphasic can move the muscles of his tongue, throat, &c., but cannot reproduce the combinations of their movements requisite for the act of speaking. Similarly the apraxic patient can move his limbs, but cannot reproduce certain combinations of movement which are required for the performance of certain acts. Apraxia has been called aphasia of the extremities. Speech is laboriously acquired by the child, chiefly through an ever-increasing store of auditory images, whereas for the acquisition of movement—in the wide sense of limb movement—he is to a great extent dependent on visual and kinæsthetic ideas. As the motor part of speech depends almost entirely on the calling up of auditory word images, so the awakening of visual and kinæsthetic images is essential for the execution of limb movements. If the patient cannot revive auditory word images he cannot speak spontaneously, though there is no paralysis of the muscles concerned; if he cannot revive kinæsthetic images he cannot move his limb spontaneously, though it is not paralysed.

Aphasia may be determined by lesions of the centripetal limb of the psycho-physical arc resulting in word-deafness and word-blindness. The existence of these entails aphasia. Similarly, agnosia may entail defects of motility. We have already seen that word-deafness and word-blindness are merely special varieties of mind-blindness and mind-deafness, *i.e.*, of agnosia.

Agraphia and (instrumental) amusia are varieties of apraxia, since in a pure state they are affections of motility where there is no paralysis or incoördination. They are, however, highly complex disturbances. The idea of a word is a combination of the auditory image of the word's sound, the visual image of its written or printed appearance, the speech kinæsthetic image, and the graphic kinæsthetic image. Writing is the result of the excitation of the centres for graphic kinæsthetic ideas, and these may be stimulated from the auditory image centre, the visual image centre, the speech kinæsthetic centre, or from the centres for ideas of objects. There may therefore be considerable disturbance of one or other receptive centre without abolition of the power of spontaneous writing. Should the afferent side be impaired to any extent, we should have agraphia of sensory origin. But the afferent apparatus may be perfect, and yet the patient may be unable to revive graphic kinæsthetic images; he is agraphic, without any paralysis; he has apraxia of the movements for writing.

There are cases on record where an individual has been unable to play a musical instrument, with the working of which he was familiar, as the result of some lesion. He has no motor affection whatever beyond the fact that he cannot make the requisite movements of fingers and wrist. Innervation of the cortical area concerned is impossible, although the patient may be able in idea to sketch the movements correctly; if he cannot revive the kinæsthetic or visual elements in what has been called the working-out idea of the movement, he cannot voluntarily effect the corresponding innervation in the area for movements of the extremities.

It is undesirable to venture farther at present along the lines that have been merely indicated; another occasion will be utilized to discuss these questions adequately.

PATHOLOGICAL ANATOMY.

The localization of the pathological processes which determine the production of the various types of agnosia is well known. Since the important experiments of Munk on the occipital cortex vast material has accumulated to corroborate his views on the localization of mind-blindness, and our knowledge of the cortical areas concerned where other forms of agnosia are clinically manifest is almost equally exact. Thanks to the labours of many scientists and clinicians, the functions of a considerable portion of the cerebral cortex are thoroughly established, and the demonstration of the frequently transcortical nature of the changes determining the agnosias leaves no room for dispute. In regard, however, to the lesions which underlie ideational agnosia, or ideational apraxia, for that matter, there is little to be said that is definite. It is clear, from our sketch of the psychological basis of these conditions, that they can only be caused by a general disintegration or dissociation of centres that normally are in harmony, and such a dissociation is not likely to occur from any local or focal change. We have seen instances of these ideational apraxias and agnosias in alcoholism, senile dementia, delirium, post-epileptic confusion, &c., where, under the influence of some toxin or some general pathological process, the function of the whole cortex must be seriously at fault. Yet even in these cases there is no valid reason why the work of analysis should not eventually enable us to subdivide and localize, if we proceed slowly and surely from the known to the unknown. Bonhoeffer [7] has been led, from a study of the delirium of alcoholism, to maintain that acute exacerbations in that condition may produce clinical symptoms which point to definite and localizable areas of the cortex.

It has happened that in cases where the clinical picture included apraxia the changes in the brain, subsequently disclosed, were too widespread to be of any localizing importance. Stransky [76] had a patient who presented the symptoms of echolalia and echopraxia, paralexia and paragraphia, and typical perseveration, whose brain was subsequently found to be in a state of diffuse cerebral atrophy, apparently most marked in the neighbourhood of the left supramarginal gyrus. Marcuse's [54] patient, who presented characteristic apraxic symptoms, with gross defect of memory and incapacity for retaining impressions, was an arteriosclerotic, and on examination there was discovered simply a diffuse atrophic change in which no localisation was possible. Pick [67] has described a case of mixed apraxia in so-called senile dementia, where the morbid appearances were those of cerebral atrophy. Nevertheless, he also holds that we are learning to regard dementia as a mosaic of partial dementias, localized or localizable, and that this has an obviously important bearing on the question of apraxia. He suggests that differences in the degree of the atrophic change may be found in association as opposed to projection cortical areas.

It is more with the pathological anatomy of motor apraxia that we are here concerned. Since the publication of Liepmann's case he and Maas [51], van Vleuten [78], Hartmann [19], Abraham [2], and others have reported cases of motor apraxia which are of the first importance, inasmuch as clinical observation has been followed by complete pathological examination. In the succeeding paragraphs the term apraxia, unless otherwise qualified, is used to signify motor apraxia in Liepmann's sense.

The original case of apraxia (Liepmann's) is somewhat unsatisfactory from the pathological standpoint. It will be remembered that the patient's state was one of motor aphasia and right-sided apraxia, with considerable alteration in cutaneous and deep sensation, weakness of the left side of the face, and bilateral apraxia of head, neck, and face; in addition, he exhibited a form of mirror writing in his left hand, which was also somewhat clumsy in performing certain tests, and occasionally showed the phenomenon of "tonic perseveration." The patient's condition altered very considerably for the worse before he died. At the *post-mortem* it was found that the whole of the corpus callosum, with the exception of the splenium, was softened, and contained scarcely a single nerve element. In the left hemisphere there were two foci of softening in the white matter underneath the first and second frontal convolutions, at the area where the callosal[1] fibres enter the hemisphere, extending partly under the third frontal. In addition, there was a large subcortical cyst beginning under the lower third of the post-central gyrus and spreading back through the parietal lobe beneath the supramarginal gyrus to end at the posterior part of the angular gyrus. In the right hemisphere was a focus of softening in the internal capsule, involving chiefly the fibres for the left face, arm, and leg, and another one in the neighbourhood of the supramarginal and angular gyri. If we refer for a moment to the scheme of the sensori-psycho-motor arc, we are reminded that apraxia is caused by an interruption in the path *v—i*, in other words, that the sensomotorium is isolated from the rest of the cortex. Liepmann predicted a series of lesions in the left hemisphere of his patient sufficient to cut off the Rolandic area from the rest of the brain, and his theory is confirmed by the findings at the autopsy. The objection has been raised by von Monakow [57] that it is a common and not always justifiable custom to associate the chief clinical symptom with the chief pathological lesion. Liepmann's patient suffered from arteriosclerosis, and in cases of generalized cerebral vascular sclerosis no insignificant part of the local or focal symptoms may be due less to direct interruption of tracts than to the effect of deficient nutrition on distant parts of the cortex. This doctrine of "diaschisis" (*Fernwirkung*) is considered by von Monakow to be of special importance in cases where there is disturbance of associations, as in apraxia. Be this as it may, the lesions in Liepmann's first case were sufficiently definite to suggest further study along similar lines.

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[1] Callosal is used in the sense of belonging to the corpus callosum.

In 1905 the same observer published a paper [42] based on the results of the examination of 89 patients, 42 of whom had left hemiplegia, 41 right hemiplegia; 5 had aphasia but no hemiplegia, and 1 was apraxic only. In these cases the non-paralysed hand and arm were carefully tested as regards their power to perform certain movements. Nearly all the left hemiplegics were able to execute given movements with the right (non-paralysed) arm. No fewer than 20 of the 41 right hemiplegics failed to execute the desired movements with the left (non-paralysed) arm. Of these 20 but 14 were aphasic; in other words, 6 non-aphasic right hemiplegics were unable to make certain movements with the non-paralysed left arm. Of the 21 right hemiplegics who were not apraxic in their left arms only 4 were aphasic. The first general conclusion is that apraxia is chiefly found with supracapsular lesions, especially with those which occasion paralysis of the right arm. That the patients were not word-deaf is clear, because in other ways they understood the requests, and it was noted that no improvement took place even though the examiner made the correct movement before their eyes for them to imitate. Again, apraxia and aphasia are not inevitably associated. The facts indicate that what the left hand can do is not in great part its own (*i.e.* the right hemisphere's) possession, but is loaned to it by the left hemisphere.

Only a few months ago Liepmann and Maas [51] read an important communication to the Medical Society of Berlin concerning a patient with right hemiplegia. He had complete agraphia in the left hand and severe general apraxia of the left upper extremity. The agraphia was evidently part of the apraxia. *Post mortem,* the right hemiplegia was accounted for by a lesion in the pons, while the right hemisphere was normal throughout, and in the left hemisphere there was a lesion of the first frontal convolution and of part of the paracentral lobule, and destruction of almost two-thirds of the corpus callosum on the left side. It would be difficult to exaggerate the importance of this case, as we shall see immediately.

In the discussion which followed Rothmann [73] said that he had had two left-handed patients with left hemiplegia and right apraxia. They had agraphia of the right hand as well, though they could speak and read. On the analogy of the preceding case these latter cases seemed to show that the right apraxia was the sequel of the lesion in the right hemisphere.

About the same time an equally significant case was recorded by van Vleuten [78]. The patient had been sent to an asylum with a diagnosis of dementia paralytica. He had neither word-deafness nor word-blindness, but he experienced slight difficulty in finding words and was occasionally paraphasic. His right hand and arm, and to a less extent the leg, showed a general tremulousness which increased with muscular effort, and in addition they presented the feature of "tonic perseveration" already referred to, and this in a pronounced degree. Once the patient grasped anything in his right hand he was unable for a time to relax his grasp in spite of every effort; the same phenomenon was observed in other muscular groups in the arm, and to a less extent in the leg. The tremulousness and the perseveration mechanically hindered the execution of various movements with the limb, but as far as observed it was certainly eupraxic. The left hand showed a fine tremor, and in addition the left arm and hand were markedly dyspraxic or apraxic, in spite of the examiner's performing the correct movements in front of the patient. There was no paresis discoverable, but the patient either failed to execute a given movement at all or made a quite erroneous one (*Bewegungsverwechselung*).

Under observation his state gradually became worse, his right limbs became weaker, and the tremor disappeared; then they became dyspraxic, though never to the same extent as the left, and finally they were completely paralysed. His speech failed greatly before death. From beginning to end of the case neither optic neuritis nor any of the cardinal general symptoms of intracranial tumour was present. At the autopsy a large sarcoma was found in the left hemisphere, which had destroyed the white substance of the limbic gyrus and the cingulum, the whole of the left half of the corpus callosum and part of the right genu of the same, and the centrum semiovale of the frontal lobe. The cortex of the three left frontal convolutions was intact. The accompanying drawing (Fig 3) is copied from van Vleuten's paper, and shows the condition in a coronal section at the level of the tips of the temporo-sphenoidal lobes.

The extreme instructiveness of this case lies in the production of a left-sided dyspraxia by a lesion which has done little else than destroy callosal fibres. The left sensomotorium is intact, as are the cortical and subcortical areas of the temporal, parietal, and occipital lobes.

In 1907, further, Hartmann [19] adduced corroborative evidence of the importance of the frontal lobe and the corpus callosum in the determination of apraxia. His contribution contains three excellent clinical studies of apraxia, with the *post-mortem* findings in each instance.

The first case was a tumour of the left frontal lobe, involving the left half of the corpus callosum, destroying the genu and sending a process through to the white substance of the right frontal lobe. It implicated the lenticular and caudate nuclei, and pressed on the internal capsule. The cortex of the left frontal pole was destroyed, but the posterior third of the upper and middle frontal gyri was intact for the depth of about 1 cm. Clinically, the patient showed marked distaste for spontaneous movements, and lay for hours in one position, with eyes closed. All movements in response to sensory stimuli were performed very deliberately. There was no particular weakness of the right arm or leg. Complete apraxia existed for right hand movements, while those of the left hand, if at all complicated, became apraxic.

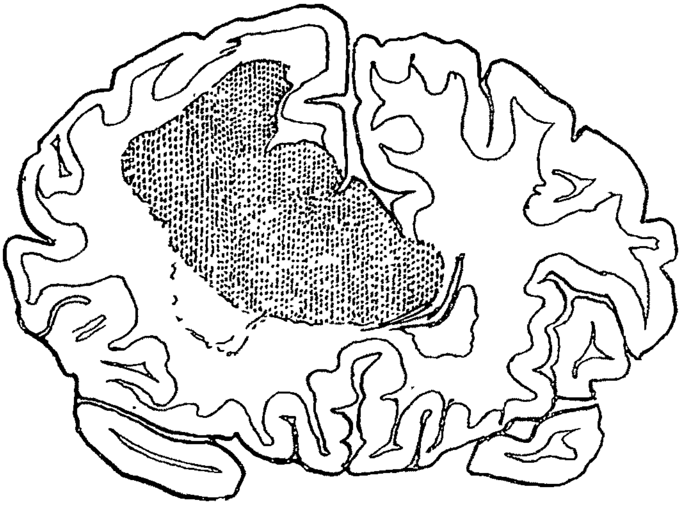

FIG. 3 (*after van Vleuten*).

In the second case there was a tumour of the corpus callosum, which spread along the mesial aspect of the left hemisphere as far as the calcarine fissure. The central gyri and projection paths were not primarily involved, and secondarily only in so far as changes in them from corpus callosum degeneration were concerned. Of the elaborate clinical picture which this patient presented we need only remark that there was more or less complete apraxia of the left hand, while movements were correctly, though very slowly, executed by the right. If his eyes were closed, the right hand moved more slowly, sometimes came to a standstill, sometimes became apraxic.

Among the many interesting features of this case, of which I have given the merest sketch, is the difference in the function of the two upper extremities, though neither was paresed nor paralysed, nor was there any sensory loss. So long as the impressions from various sensory centres served to stimulate motility, so long was the patient able to perform eupraxic movements, however deliberately, with his right hand and arm; but in the case of the left arm the coöperation of the other senses was insufficient, and his apraxia amounted almost to akinesia. Where both hands were used for some object he was hopelessly apraxic. From memory alone he was unable to make any movement with his left arm, and very few with his right.

In the third case there was a cyst in the middle of the right frontal lobe, independent of the lateral ventricle, which injured the cortex over the second right frontal convolution and reached the under surface of the cortex over the third frontal. Clinically, the patient was unable to grimace on request or to imitate grimaces; he had difficulty in making given movements with his tongue; his right arm was normal, while with his left he frequently failed to perform set movements, making either amorphous ones or else little movement at all. There was no parapraxia. In the handling of objects no defect was observed on the right side, on the left amorphous or akinetic movements were made. With either hand he imitated well. Movements of expression (beckoning, threatening, &c.) were good on both sides. Bilateral use of the hands in indicating the nature of objects was accurate.

Thus a cortical lesion of the second right frontal convolution produced a left-sided dyspraxia, in which the simple use of objects in the left hand was greatly impaired, while the imitation of movements was perfect. The fact that two-handed movements were quite good is of peculiar interest, as it seems to suggest that the left hemisphere plays an important part in the initiation of what is accomplished by the other.

Maas [53] has recently reported a case of slight right hemiplegia and slight aphasia, where the patient can write spontaneously or to dictation with his right hand, while his left hand is typically apraxic, with conservation of motility and sensation. With this left hand he can copy movements which he cannot initiate. In this instance there is no corroboration by *post-mortem* evidence, but Maas indicates in the accompanying diagram (Fig. 4) his view of the situation of the lesion.

In June, 1907, Liepmann [48] published a paper on the physiology of the corpus callosum, based on his own cases and on some of those that have just been mentioned. He repeated his view that in right-handed persons, who constitute about 95½ per cent., the left hemisphere exercises a potent influence over the movements of both sides of the body, and that many of the movements of the left limbs are initiated in the left hemisphere. Most people can beckon or execute a threatening movement with the left arm, but these movements are impossible in certain left hemisphere lesions. The opinion expressed by Hartmann is that the first and second left frontal convolutions constitute a special association centre for the aggregation of individual movements of either side of the body into movement-complexes and for the conversion of ideas of movement into the corresponding innervation. Liepmann holds, rather, that the right limb-centres depend in a way on the left limb-centres, and that the former are guided by the latter through the medium of the corpus callosum. In the accompanying diagram (Fig. 5) he elucidates his hypothesis.

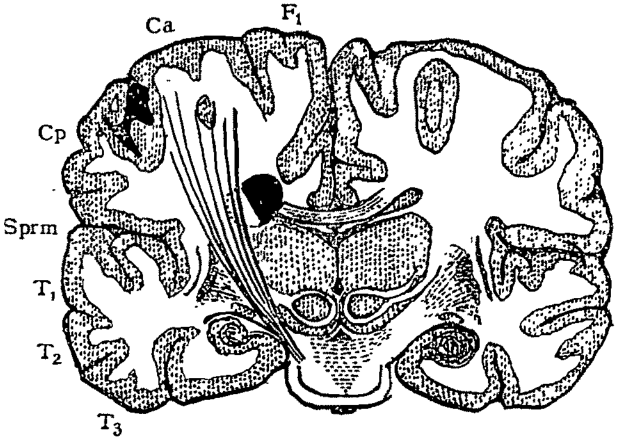

FIG. 4 (*after Maas*).

(1) A lesion of the left arm centre produces greater or less paralysis of the right arm, and the left, deprived of the guidance of that centre, becomes dyspraxic.

(2) A subcortical lesion of the Rolandic area interrupts the projection fibres to the right hand, as well as the callosal fibres to the right hemisphere, according to the situation and extent of the lesion, and produces a result similar to (1).

(3) A lesion of the internal capsule, where the commissural fibres are sharply differentiated from the pyramidal, causes right-sided paralysis, but there is no left-sided apraxia.

(4) A lesion in the corpus callosum, of particular size and position, determines a left-sided dyspraxia from loss of the lead of the left arm centre over the right arm centre, while the right hand need be neither paralysed nor apraxic. A similar effect would be produced by a lesion in the left centrum ovale, which catches only callosal fibres.

(5) A fifth possibility is that a limited lesion in the white matter of the right frontal lobe may cut across the path of the fibres passing from the left frontal lobe, *via* the corpus callosum, to the right arm centre in the right hemisphere, without injuring the projection fibres from that arm centre to the left hand. In this case we should have a left-sided dyspraxia from a right-sided lesion. It is possible that Hartmann's third case falls into this category.

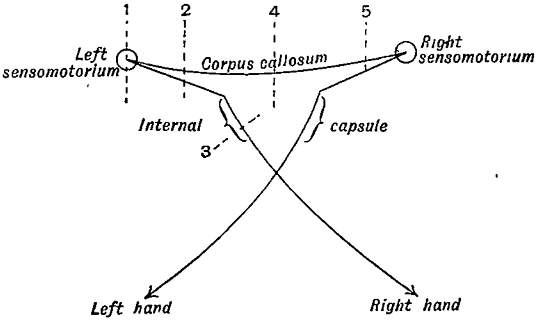

FIG. 5 (*after Liepmann*).

1. Cortical lesion. 3. Capsular lesion.
2. Subcortical lesion. 4. Lesion of corpus callosum.
5. Subcortical lesion.

Liepmann and Maas's case, van Vleuten's case, and Hartmann's cases are therefore of peculiar interest in view of this schematization of callosal lesions.

Abraham's [2] case was one of more or less general cerebral atrophy from arteriosclerosis. It is true this atrophy of the convolutions was more marked in certain areas than in others, notably in the region extending from the post-central convolution to the occipital pole, chiefly on the left side, and in particular in the upper part of the cortex, behind the mesial end of the fissure of Rolando. It will be remembered that in

Liepmann's first case much of the region lying posterior to the ascending parietal, stretching towards the supramarginal gyrus, was involved. The more minute analysis of Abraham's case has not yet been published, and in his communication there is no reference to the corpus callosum. While the frontal lobes were atrophied, there was apparently no lesion in the centrum ovale.

At the Frankfurt Congress of 1907, Westphal [84] showed an excellent case of mixed apraxia affecting the left hand much more than the right. Apart from the motor apraxia, some of the phenomena presented by this patient were clearly due to a degree of agnosia, a feature which has been often remarked. In this case, also, only a brief report of the pathological condition has as yet been published. There was general arteriosclerosis, with internal hydrocephalus affecting the left lateral ventricle more than the right. It is scarcely desirable to refer further to the findings, as the pathological examination is incomplete; the author says, however, that to the naked eye there was no noticeable change in the corpus callosum.

LOCALIZATION AND CONCLUSIONS.

If we now succinctly summarize the results of clinical research and pathological investigation, we must feel that the localization of apraxia, of motor apraxia at least, is by no means so elusive as might have been suspected only a year ago. Those who have become most familiar with the subject are the most cautious in expressing opinions which are other than tentative. Nevertheless, certain facts impress themselves on us.

In the first place, apraxia may be, and has been, definitely proved sometimes to be unilateral. This unilaterality of apraxia is a fact of the greatest import. Its occurrence in one limb only, or on one side only, is already a step towards localization.

Further, apraxia is associated with lesions in the left hemisphere much more frequently than with lesions in the right. These lesions are—if we are allowed to argue from existing material, we have no hesitation in adding always—supracapsular in situation. That is, the lesions which produce apraxia are cortical or subcortical.

Again, the apraxia which results from left hemisphere disease may be homolateral or heterolateral. Recent carefully observed cases have established the significance of disease of the corpus callosum in the development of apraxia, and have supplied evidence of impairment of that structure where the apraxia is homolateral.

Apraxia has occurred where the whole of the cortex of both hemispheres has been normal, with the exception of the left frontal area. It has been present where the fibres from the upper two frontal convolutions in particular, apparently not so much projection as association fibres, have been interrupted.

Is there, then, a "centre" for eupraxia of both sides of the body in the frontal cortex on the left side? Does this "centre" bear the same relation to the motor centres for the limbs in the sensomotorium that Broca's centre does to the cortical area for the innervation of throat, lips, tongue, larynx, &c.? Some of the facts we have adduced favour this theory, and Hartmann [19] has lent the weight of his support to it. That the isolation of the left frontal cortex from the corresponding area of the opposite side determines apraxia is beyond question. That apraxia results when the left sensomotorium is functionally isolated from the rest of the cortex is also apparently well attested. It is difficult, however, to say whether the separation of the sensomotorium from the frontal cortex, or from the rest of the homolateral (occipital, temporal, &c.) cortex, or from both, is the essential element. Possibly an agnostic apraxia is determined where the associations of the sensory cortex with the upper frontal cortex are severed, while the separation of the latter from the motor cortex produces the motor variety.

The accompanying diagram (fig. 6), modified from Liepmann [48], may with advantage be combined with his other diagram representing callosal lesions.

A lesion at 1, if deep, will have as sequel the paralysis and apraxia already noted. A superficial cortical lesion here will be followed by loss of kinæsthetic ideas (Meynert's motor asymboly; Heilbronner's cortical apraxia). The motor apraxia of Liepmann's first case resulted from a lesion as at 2, whereby the left sensomotorium was cut off both from the frontal and the rest of the cortex of both sides.

Thus there are different groups of lesions of the left hemisphere which determine a homolateral or a heterolateral apraxia. We must repeat that this apraxia coexists with perfect conservation of ordinary motility, and therefore *must be looked for.* I took the notes of a case[1] of left frontal tumour some time ago, where ordinary examination revealed no abnormality in the left arm, and nothing further was remarked. Subsequent exploration discovered a left frontal tumour growing into and invading the anterior part of the corpus callosum. It is at the least possible that such a case might have presented dyspraxic phenomena in the left hand, *had they been looked for.*

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[1] H. C., under Sir William Gowers.

Our conception of the frontal lobe, and of its functional relation to the corpus callosum, the sensomotorium, and the rest of the cortex, cannot but be widened as a result of these discoveries, and with this widened conception our dissatisfaction with the indiscriminate use of such terms as "impaired intelligence," "partial imbecility," "poor memory," "defect of movement," and the like must be proportionately increased.

It is a favourite dictum of Dr. Hughlings Jackson's that the "study of the thing caused must precede the study of the cause of the thing," and we may assure ourselves that the patient eliciting of facts, too often overlooked, even in such cases as a simple hemiplegia, will be of material service in removing the reproach that is implied when we are forced to allude to the "silent areas of the brain."

Diagrammatic horizontal section.

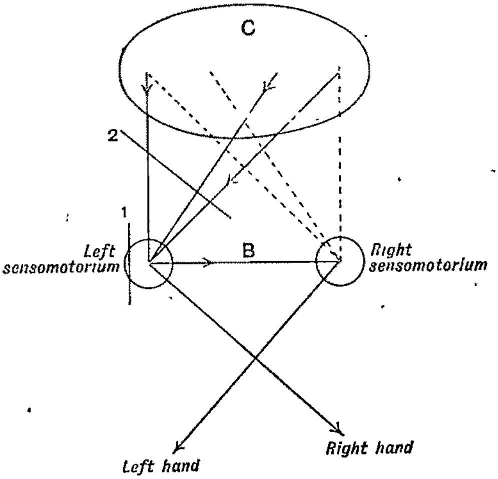

FIG. 6 (*modified from Liepmann*).

B Corpus callosum. C represents the rest of the cortex.

SCHEME FOR THE EXAMINATION OF APRAXIC PATIENTS.

The appended scheme for the examination of apraxic patients makes no pretence to psychological completeness. Theoretically, a logical scheme should begin with the afferent apparatus; and in addition, certain terms such as attention should not be included under a general heading, since they are, strictly speaking, psychomotor in nature; others, such as orientation, are psychosensory. It is more satisfactory, however, from a practical point of view, to commence with a general survey. The part of the scheme which would concern the question of speech has been purposely omitted. Tests for the psychosensory side of the psychophysical arc are referred to without the detail that must be supplied in full, if at all. The psychomotor part is sketched more analytically, and in it are included various methods employed by Hartmann. In a useful little paper Liepmann [44] also has indicated modes of procedure in apraxic cases.

(1) *General Psychical Condition.*

Attention (active and passive), memory (varieties of amnesia), capacity for retaining impressions, orientation in time and space; temperament, mood, depression, excitability, emotional reaction; suggestibility; deliberation, judgment, reasoning, association of ideas, hallucinations, delusions; attention to or neglect of himself, behaviour in eating, dressing, &c. Sleep, dreams, headache, giddiness, &c.

(2) *Psychosensory.*

(*a*) Simple perception, in field of sight, smell, hearing, taste, cutaneous sensibility, muscular sense.

(*b*) Recognition (and indication of recognition) of sensory impressions in regions of sight, smell, hearing, taste, cutaneous sensibility, muscular sense: localization of sensory impressions.

(*c*) Memory of, and ability to recall, former sensory impressions in same regions.

(3) *Psychomotor.*

[Throughout this examination look carefully for perseveration.]

(*a*) General: Spontaneity, initiative, general response to stimuli, immobility, restlessness, &c.; involuntary movements; range and power of voluntary movements.

(*b*) *Movements conditioned by visual stimuli.*

(i.) What response does the patient make to objects held in front of him? Does he take hold of them, with right hand, left hand, both hands? Does he respond to gestures made in front of him (threatening, inviting, &c.)?

(ii.) Does he imitate movements performed in front of him (right hand, left hand, both)? Is there any echopraxia?

(c) *Movements conditioned by auditory stimuli.*

(i.) Can he make simple movements of parts of his body on request? Ask him to snap his fingers, point his fingers, separate his fingers, make a fist, &c. (either hand, both). Ask him to cough, swallow, spit, sniff, take a deep breath, sigh, yawn, put out his tongue.

(ii.) Ask him to make movements of expression. Can he threaten, beckon, make a wry face, throw a kiss, salute, clasp his hands as in prayer, &c.?

(iii.) Can he make movements for a definite object, the material not being at hand? Ask him to show how to knock at the door, catch flies, play the piano, ring a bell, count out money, turn a barrel organ, draw a cork, thread a needle, sew, &c. (The examiner ought to consider the patient's sex in this connection; the patient's occupation should also be a guide.)

(iv.) Can he, on request, make purposive movements with the objects in his hands? Can he light a match, smoke, pour out water, tie a knot in string, &c.? (*Cf.* iii., above.)

(v.) Ask him to imitate simple movements made in front of him (either hand, both hands).

(vi.) Can he make reflexive movements on request? Ask him to touch various parts of his own body which he can see, to scratch or tickle himself, to pull his moustache, &c. Ask him to touch various parts of his body which he cannot see: request him to put his hand on the back of his head, to touch his nose with his finger, to put his hand in the middle of his back, &c. Does he touch corresponding parts on examiner better? Can he make reflexive movements with objects in his hand? Ask him to brush his hair, comb his beard, brush his teeth, blow his nose, &c.

(d) *Movements conditioned by tactile and kinæsthetic stimuli.*

(i.) Give objects to the patient; how does he hold them? how does he use them? If he is shown the way, does his handling of them improve? Does it make any difference whether his eyes are open or shut? Can he continue a movement once begun if he shuts his eyes?

(ii.) Put limb passively into a certain position. Can he imitate it with the other? Any difference if eyes are shut? Can he imitate from right to left and from left to right?

(*e*) Movements of the arms during general movement of the body. Observe what he does with his arms when sitting down, rising up, walking, &c.

[Throughout the examination it is desirable, as far as possible, to test the hands separately, and then together.]

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PUBLICATIONS RECENTLY RECEIVED.

[*Notes on a book under this heading do not preclude a subsequent review.*]

Beiträge zur Kenntnis der Heine-Medinschen Krankheit [Poliomyelitis und verwandter Erkrankungen]. Von Dr. IVAR WICKMAN. S. 292. Berlin: Karger, 1907.

In this interesting work the author puts together a clinical account of those acute diseases which affect the motor side of the nervous system, of which poliomyelitis acuta is the best-known example. He traces the epidemics which have occurred in Sweden, giving local maps and tables of incidence. It forms a valuable companion to the author's previous work on poliomyelitis, which dealt mainly with the pathology. We cannot help regretting the title of this book, which obscures its contents.

Die Funktionen der Nervencentra. Von Professor W. VON BECHTEREW. Deutche Ausgabe in Verbindung mit dem Verfasser redigirt durch Dr. RICHARD WEINBERG. Erster Heft, S. 691. Jena: Gustav Fischer, 1908.

This important work is the first half of an exhaustive description of the position and function of the centres and paths in the nervous system. After an introduction of eighty-two pages, the author passes to the spinal cord and medulla oblongata; here he describes the nervous mechanism underlying all the visceral functions. The present volume ends with a consideration of the conducting paths in the spinal cord. On the appearance of the second volume we hope to give this work a fuller notice.

The Influence of Alcohol and other Drugs on Fatigue. The Croonian Lectures, delivered at the Royal College of Physicians in 1906. By W. H. R. RIVERS, M.D. Pp. 136. London: Edward Arnold, 1908.

These lectures contain a description of the experiments made by the author on the influence of caffeine and alcohol on muscular work and mental fatigue. The former was measured by means of the ergograph and the latter by various modifications of Kraepelin's method. Every precaution was taken to avoid suggestion; control mixtures indistinguishable from those containing the drug under investigation were taken by the subject. In many ways this work is a considerable advance in the psychological study of the influence of drugs on man. The literature of the subject is fully considered. The book is clearly written and admirably printed.

Injuries of Nerves and their Treatment. By JAMES SHERREN, F.R.C.S. Pp. 310. London: James Nisbet, 1908.

A thoroughly practical treatise on nerve injuries and their treatment, based on original research and clinical observation. The author first describes the symptoms and signs produced by complete division of a peripheral nerve and contrasts it with those which follow incomplete division. Differential diagnosis and treatment are carefully considered. He then passes to the methods of recovery and to the signs peculiar to each of the larger nerve trunks. The book is illustrated with photographs and diagrams; it is well printed and is not too large for the pocket. It will be of great value to senior students and practitioners, and the neurologist will find much both of practical and theoretical interest.

The Labyrinth of Animals. By ALBERT A. GRAY, M.D., F.R.S.E. Vol. ii. Pp. 252. London: Churchill, 1908.

The first volume of this remarkable work appeared in 1907. The author succeeded in removing the bone so as to leave the membranous labyrinth intact. Each specimen was then photographed stereoscopically. This volume deals with rodents, insectivora, cetacea, marsupials, the principal groups of birds, reptiles and amphibians.

Diseases of the Nervous System. Edited by ARCHIBALD CHURCH, M.D. An authorized translation from "Die Deutsche Klinik" under the general editorial supervision of JULIUS L. SALINGER, M.D. Pp. 1205. London: Sidney Appleton, 1908.

This translation of a German text-book of diseases of the nervous system will be of use to post-graduate and senior students; the neurologist will find little which is not familiar to him. The sections are unequal, as must be the case in a book compiled by thirty-two contributors; some, such as that of Wernicke on Aphasia, are unusually full from the author's point of view, whilst others, such as that on Cerebral Hæmorrhage and Embolism, occupy six pages only.

Anatomy of the Brain and Spinal Cord, with Special Reference to Mechanism and Function. By HARRIS E. SAUTEE, M.D. Fourth edition, revised and enlarged. Pp. 453. London: Sidney Appleton, 1908.

Suitable for a senior student, this book is too superficial for the trained neurologist. There is no discussion of divergent views, and controversial points are covered by an incomplete statement or the intricacies of a diagram. No references are given to the literature. Printing and general arrangement are excellent.

Psychiatrie für Aerzte und Studierende bearbeitet. Von Professor Dr. Th. ZIEHEN. Dritte vollständig umgearbeitete Auflage. S. 801. Leipzig: S. Hirzel, 1908.

A third edition of this well-known text-book. Its general plan remains unaltered, and all the principal features of previous editions are maintained. The notes in small print, containing references to the literature, add decidedly to the value of the book.

Mental Pathology in its Relation to Normal Psychology: A course of lectures delivered in the University of Leipzig. By GUSTAV STÖRRING, Professor of Philosophy in the University of Zürich. Translated by THOMAS LOVEDAY. Pp. 298. London: Swan Sonnenschein & Co., 1907.

A series of lectures dealing with the bearing on psychology of the nature and genesis of hallucinations and illusions, of aphasia and amnesia, of imperative ideas and delusions. Two lectures are devoted to a consideration of feeling and one to manifestations of the morbid will.

The Psychology of Alcoholism. By GEORGE B. CUTTEN, B.D., Ph.D. Pp. 357. The Walter Scott Publishing Co., New York, 1907.

A general discussion of the phenomena of alcoholism and a review of the various forms of treatment. It contains no original experimental or clinical observations.

Transactions of the Ophthalmiological Society of the United Kingdom. Vol. xxvii. Session 1906-1907. Pp. 311. London: Churchill, 1907.

The reports on hereditary diseases, and especially Nettleship's history of congenital stationary night-blindness in nine consecutive generations, are for the neurologist the most interesting contents in this volume. This paper will certainly become a classic, and should be a model for all who work on hereditary disease.

Transactions of the Ophthalmological Society of the United Kingdom. Vol. xxviii. Fasc. 1. Pp. 94. London: Churchill, 1908.

The only paper of neurological interest is that by Nettleship on "Some Cases possibly allied to Amaurotic Family Idiocy." He propounds the question: What would be the fundus changes in a patient with Waren Tay-Sachs disease who succeeded in living? and suggests that some cases of congenital amblyopia with day-blindness and total loss of colour sensation may be allied to this disease.

Writers of "Original Articles and Clinical Cases" are supplied free of charge with 50 copies reprinted in the form in which the paper stands in the pages of "Brain." If reprints are required in pamphlet form, with wrapper, title-page, &c., and re-numbered pages, they must be ordered, at the expense of the writers, from Messrs. BALE, SONS & DANIELSSON, Ltd., 83-91, Great Titchfield Street, London, W.

Members of the Neurological Section of the Royal Society of Medicine can obtain the Index of "Brain" for the Volumes I. to XXIII. inclusive, that is, from its commencement to the end of 1900, from Messrs. MACMILLAN & CO., Ltd., St. Martin's Street, London, W.C., at the price of 6s. 6d., post free.

To those who are not members of the Neurological Section of the Royal Society of Medicine the price is 8s. 6d. net, and the volume may be obtained through any bookseller.

EDITOR.

[JULY, 1908.]

BRAIN.

PART II., 1908.

Original Articles and Clinical Cases.

ON THE DEVELOPMENT OF THE LARGE COMMISSURES OF THE TELENCEPHALON IN THE HUMAN BRAIN.

BY J. W. LANGELAAN, M.D.,
Professor in the University of Leyden.

THE brains of five human embryos, ranging from the beginning of the fourth month to the end of the eighth, were at my disposal for these researches. Two of these brains, one of the beginning and the other of the middle of the fourth month, were cut into a series of frontal sections. These sections were stained by means of hæmatoxylin and eosin. Of the three other brains only a median section was made for studying the later stages of development of the corpus callosum.

The sections I made of the brain at the beginning of the fourth month were 20 μ thick and slightly deviated from the frontal plane, so that the sections meet the hemisphere, which is on the left in the photographic reproductions, in a more posterior level than the one on the right. In this brain the anterior commissure is so far histologically differentiated that it can be recognized as a strand of a fibrous structure; among the fibres are spread the nuclei of glia cells. The diameter of the commissure amounts to 0·4 mm. The commissure lies partly in the lamina terminalis, covered from behind by the ependyma of this lamella. The more anterior part of the commissure probably exceeds the limit of the lamina terminalis. This limit cannot be traced out with certainty, because in front of the lamina, and in direct continuity with it, the mesial surfaces of the pallium are united.

The corpus callosum and the fornix are also recognizable, but the tissue composing these systems is not so far differentiated as that of the anterior commissure. Both systems are built up by a reticular tissue, the meshes of which are irregularly shaped, with a prevalence of hexagonal ones. In one direction the meshes are stretched, whilst in another direction, at right angles with the first, the diameters of the meshes are pretty nearly equal. Now the direction in which the meshes are stretched coincides with the ultimate direction of the fibres which differentiate out of this meshwork. Therefore we are able to recognize in the sections different directions, in correspondence with the final course of the nerve fibres generated by this tissue. Beyond its particular structure the reticular substance of the corpus callosum and of the fornix stains more deeply with eosin than does the surrounding tissue; moreover, it is characterized by a considerable want of nuclei; only here and there glia cells with dark stained nuclei are met with. Large capillary loops are seen in the reticular substance of the corpus callosum, penetrating from the surrounding connective tissue into the substance of the commissure.

If we compare the tissue of the commissura anterior with that of the corpus callosum, the difference is very noticeable. In the anterior commissure the transverse septa have largely disappeared and the longitudinal septa have become thicker, resulting in a more fibrous structure. Moreover, the fibres are united in bundles, which are wrapped up by glia cells.

In order to determine the place where the corpus callosum originates I reproduce two frontal sections through the lamina terminalis. The first of these sections (figs. 1 and 1A) just touches, at the left, the ependyma (E.l.) of the lamina terminalis (L.t.). At this place the lamina is continued in a tænia (T.), which goes over into the mesial wall of the pallium. What appears in the preparation as a tænia is the transverse section of an ependymal membrane. This fleece is the continuation of the lamina terminalis, which is bent in and then passes over into the mesial wall of the pallium. A little backwards this membrane is invaginated into the lateral ventricle forming the ependymal covering of the plexus choroideus of this cavity.

Now in the lamina terminalis, at a little distance from its superior margin, the corpus callosum (C.c.) is situated. At the left appears the lateral border of the commissure. This edge is convex and bordered by the ependymal cells of the lamina terminalis. Here the section is torn, so that at the place I indicate by crosses the connection between the lamina terminalis and the wall of the pallium is broken. Going to the right in the section, the continuation of the callosum into the mesial wall of the pallium is visible. The superior border of the commissure, so far as it lies in the lamina terminalis, is concave and covered from above by the tissue of this membrane. The inferior border, which is the direct continuation of the lateral border, is convex

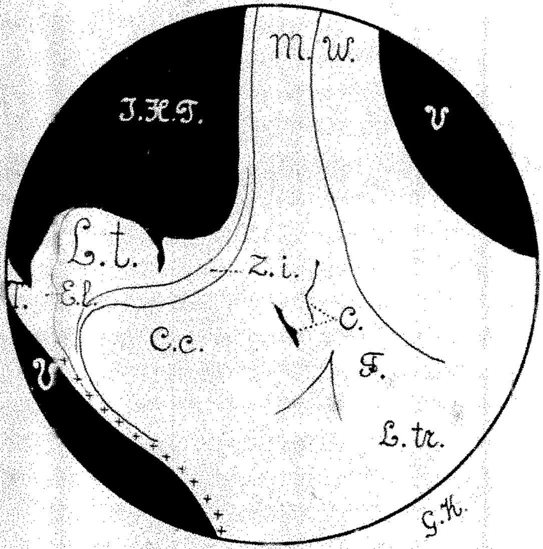


FIG. 1.

Frontal section through the lamina terminalis.

Human embryo of the beginning of the fourth month.

C., capillaries.
C.c., corpus callosum.
E.l., ependymal layer.
F., fornix.
I.H.T., interhemispherical tissue.
L.t., lamina terminalis.
L.tr., lamina trapezoidea.
M.W., mesial wall of the pallium.
T., tænia.
V., lateral ventricle.
Z.i., intermediate zone.

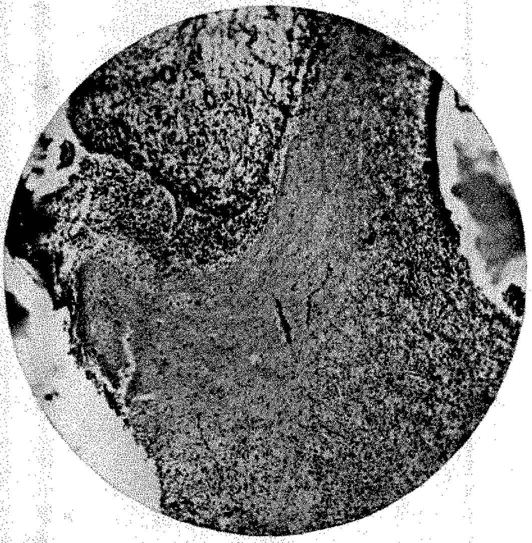


FIG. 1A.

Frontal section through the lamina terminalis.

Human embryo of the beginning of the fourth month. Photograph Zeiss obj. B.B., enl. $\frac{47}{1}$. Fig. 1 is the outline of this photograph ; the crosses in that figure indicate the place where the section is torn.

Aside from the corpus callosum, and entirely confined to the mesial wall of the pallium, lies the fornix (F). In the mesial wall the two systems cannot be distinguished. At the place where the systems diverge the difference becomes evident, the callosum forming a dense meshwork, whilst the tissue of the fornix spreads out in passing over into the lamina trapezoidea (His). Apart from the spreading out there is also the difference in the form of the meshes, those of the fornix being more stretched.

In figs. 2 and 2A I reproduce a section through the most posterior part of the callosum (C.c.) lying in the lamina terminalis. It shows this most posterior part also at a little distance from the superior border of the lamina. The tissue in which it is imbedded (Z.i.) consists of cells, the nuclei of which are more distant and stain less intensely than those of the ependyma. A narrow band of this tissue penetrates between the commissure and the ependyma, which is situated at the left and underneath the commissure. The same fact may be observed in fig. 1, where at the left a small strip of this tissue is also interposed between the callosum and the ependymal layer of the lamina terminalis. This proves that the posterior part of the callosum, though situated in the lamina terminalis, does not touch the ependyma, but is always separated from it by a thin layer of non-ependymal cells. These cells belong to the layer which in this stage of development is described by His as the intermediate layer (*Zwischenschicht*) [8 (pp. 91, *et seq.*)] of the wall of the pallium. The distance by which the most posterior part of the callosum is separated from the posterior surface of the lamina terminalis amounts to 0·1 mm.

In the more frontal region of the callosum the relations are less simple, being complicated by the union of the mesial walls of the pallium. The fronto-occipital diameter of the united part of the laminæ trapezoideæ attains to 0·32 mm. Both pallia meet in the zone of union at a sharp angle, in which the interhemispherical tissue (commonly called the falx cerebri) penetrates like a wedge. This formation is built up by fusiform cells with elongated nuclei; as to its structure, it is a lacunar tissue, the lacunæ of which are filled up with blood-corpuscles. At a little distance from the wall of the pallium the lacunæ are wide, and as such easily recognizable, but approaching the wall they become smaller, and at last are not to be distinguished from the small slits always occurring in connective tissue. In these small clefts, however, I often find one or two blood-corpuscles. For this reason I believe that at least some of these clefts have a connection with the larger lacunæ. Besides these lacunæ small blood-vessels are met with in this tissue which pass over into capillaries. Quite near the wall of the pallium the nuclei of the connective tissue are arranged with their long axes parallel with this wall. The outer surface of the pallium itself is covered by a thin layer

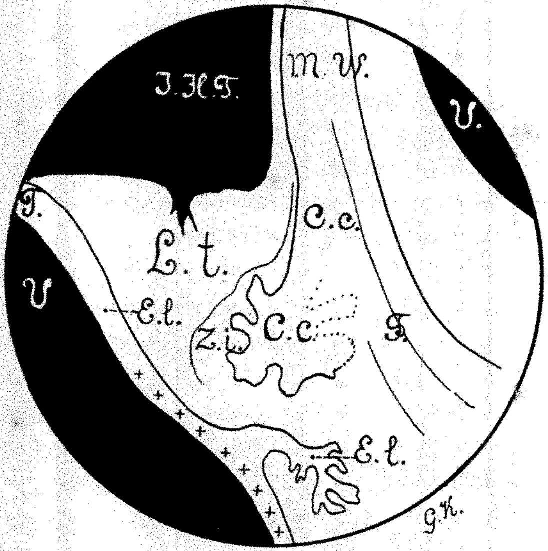


FIG. 2.

Frontal section through the lamina terminalis just touching the most posterior part of the corpus callosum.

Human embryo of the beginning of the fourth month.

C.c., corpus callosum.
E.l., ependymal layer.
F., fornix.
I.H.T., interhemispherical tissue.
L.t., lamina terminalis.
M.W., mesial wall of the pallium.
T., tænia.
V., lateral ventricle.
Z.i., intermediate zone.

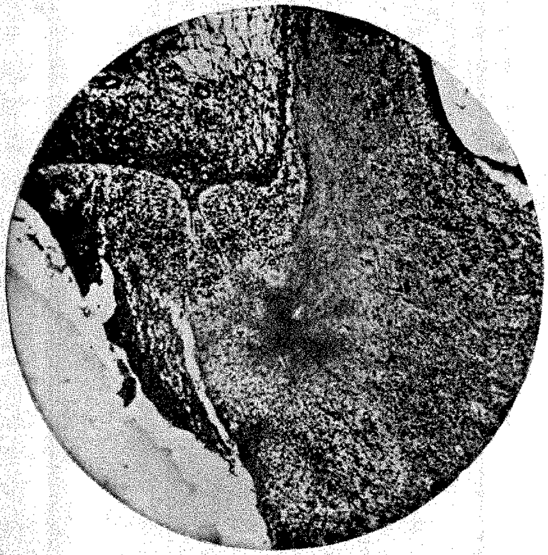


FIG. 2A.

Frontal section through the lamina terminalis just touching the most posterior part of the corpus callosum.

Human embryo of the beginning of the fourth month. Photograph Zeiss obj. B.B., enl. $\frac{47}{1}$. Fig. 2 is the outline of this photograph; the crosses in that figure indicate the place where the section is torn.

of glia cells with rounded nuclei. This sheath is one cell thick. Approaching the zone of union the elongated nuclei converge towards the top of the wedge so that this top is formed by two or three of these nuclei.' Now these nuclei are pressed together very flat, perhaps a little longer than the nuclei of the adjacent cells, and thereabove curved, or bent like an S. At some places one of these nuclei seems to penetrate a little into the substance of the corpus callosum and is less stained than the other nuclei. I should be inclined to interpret the process I just now described as a marginal atrophy of the interhemispherical tissue.

The substance of the corpus callosum along the lateral border of this wedge-shaped interhemispherical tissue shows stretched meshes; towards the top these meshes become shorter and more hexagonal, whilst at the same time they become smaller. The mesh-work itself at this spot stains more deeply with eosin. The whole structure gives the impression as if the tissue of the callosum sharply bends round the top of the interhemispherical tissue and is compressed. I think, therefore, that the growing commissure exerts a pressure upon the interhemispherical tissue and that this is the direct cause of the atrophy of this membrane.

Now this process of atrophy must be sharply distinguished from the ingrowth of capillaries into the commissure. In the brain under description these capillaries mainly penetrate from above through the superior border of the lamina terminalis. Not only capillaries, but also a larger blood-vessel, pierces this lamina. At the border of the commissure the vessel goes over into a capillary that penetrates into the callosum (C.c., fig. 1). It follows already from the bare topographical relations that the atrophy of the interhemispherical tissue and the ingrowth of capillaries from this tissue are two distinct processes, which may take place independently of each other. In most cases, however, especially in the more advanced stages of the development, the two processes are mixed up in such a manner as to make an analysis quite impossible. From the drawings of Zuckerkandl [30] I should be inclined to conclude that in the rat this is the case from the very first. Probably the difficulty which the analysis offers in this case induced the author to describe a *Durchwachsung* of the falx cerebri by the fibres of the callosum. In my opinion this statement is erroneous, as I never found free ending fibres nor rudiments from the connective tissue other than in direct connection with the blood-vessels that pierce the lamina terminalis and penetrate into the commissure.

The fronto-occipital diameter of the callosum amounts to 0·5 mm.; about one-third of this (0·18 mm.) is situated in the lamina terminalis, and two-thirds (0·32 mm.) transgress the limits of the lamina and lie in the zone of union. The thickness of the lamina terminalis attains to 0·28 mm. Fig. 3 represents these relations diagrammatically.

The most posterior part of the callosum passing over from the lamina terminalis into the wall of the pallium is recurved backwards. It may be followed for some distance in an occipital direction, reminding one of the final state when there is a forceps major. In the same way the more anterior part of the callosum is continued in a frontal direction. The fornix, which lies laterally of the callosum, cannot be distinguished from it in the more occipital region. There the two structures together occupy a triangular field with its top turned upwards. The impossibility of discriminating between the two structures is caused by the fact that in this region the fornix and the callosum have about the same direction, so that there is no appreciable difference in the shape of the meshes. At the place where the callosum passes over into the lamina terminalis the two structures diverge, and this produces a difference in the shape of the meshes in the frontal section. The fornix spreads out and goes over into the lamina trapezoidea on its way to the hypo-thalamus. In the more frontal region the fornix is no longer present and only the callosum remains in the wall of the pallium. Callosum and fornix in the lamina terminalis, as well as in the mesial wall of the pallium, are strictly confined to the intermediate layer of this wall.

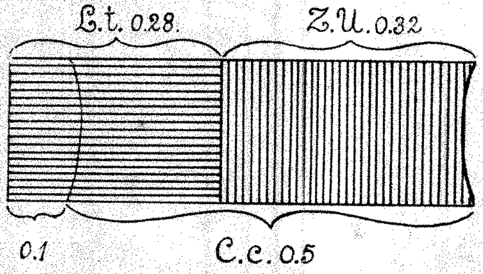


FIG. 3. Enl. $\frac{100}{1}$.

C.c., corpus callosum.
L.t., lamina terminalis.
Z.U., zone of union.

In its general features I find that the structure of the mesial wall of the pallium corresponds with the description given by His [8 (pp. 91 and 111)]. First comes an ependymal layer bordering the lateral ventricle, then a matrix (*Matrix*), next the intermediate stratum (*Zwischenschicht*); upon this follows the cortex layer (*Rindenschicht*), which is followed by a marginal zone (*Randschicht*), covered from the outside by a thin sheath of glia cells (membrana limitans externa). Changes appear in this structure at the level occupied by the callosum (*cf.* figs. 9 and 9A). The matrix layer becomes thinner, those cells arranged tangentially in respect to the surface of the pallium wall disappearing first, those radially placed disappearing next. The breadth of the intermediate layer increases, and at the same time this stratum gets richer in nuclei, especially around the fibres of the commissure; these nuclei surround this structure like a cap (C.n.). The cortex layer, like the matrix, becomes thinner, bends somewhat inwards and ends in a sharp edge at a little distance from the under border of the mesial wall of the pallium. Now, in this stage of development this ending of the cortex is not so evident as it is afterwards (figs. 9 and 9A). The difference in the density of the nuclei between the intermediate layer, the cortex and the marginal zone, at the level of the edge of the cortex, is trifling, so that it is difficult here to recognize the cortex layer. That the cortex really does end may be deduced from the fact that the nuclei of this stratum show a radial arrangement, whilst this is not the case with the nuclei of the two other strata. Therefore I cannot agree with the statement of His [8 (p. 129, figs. 84 and 86)] that the cortex layer is enlarged and forms a prominence at the external surface of the pallium.

Neither have I been able to find a fissura arcuata, but at about the same level, where it is described by Goldstein [5], the inner surface of the mesial wall shows a notch. In the frontal region this indentation begins very flat, but towards the level of the lamina terminalis it grows deeper and sharper. With the indentation of the inner surface corresponds a notch at the outer surface, which lies a little lower; at the same time the wall of the pallium grows thinner, so that the place between the two notches is the most slender part of the pallium wall. In my sections there is at this place a beginning of folding in of the wall, which is doubtlessly artificial. I therefore agree in this matter with Hochstetter [9], Mall [14], Retzius [20], Goldstein [6], and others who consider the folds of the wall of the pallium in these stages of development purely artificial.

The brain of the embryo of the middle of the fourth month was not so well preserved as the first one. The embryo, when born showed symptoms of luetic infection. In the frontal region, at the place of the arched fissure, the wall of the pallium on both sides is folded in exactly as is drawn by His [8] in fig. 86. This fold in the region of the callosum, goes over into a rupturing of the wall. At the place of the rupture the walls are bent in, so that these parts of the mesial walls, which are adjacent to the callosum, diverge abnormally. This divergence influences the form of the interhemispherical tissue, but not in such a degree as entirely to disturb the normal relation of this structure to the mesial wall of the pallium. It appears, from a comparison of the various dimensions, that this brain agrees in all respects with that described by Goldstein [5]. The sections I made varied in thickness; some are 15 μ, some are 20 μ, according to the region of the cerebrum.

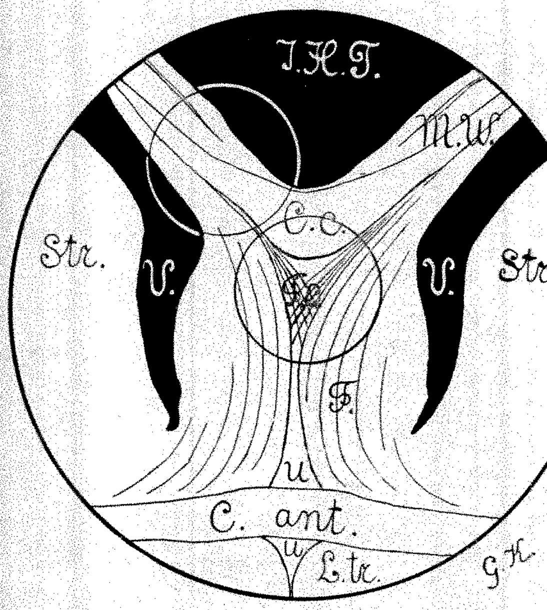


Fig. 4.

Frontal section through the zone of union at the more posterior part of the callosum.
Human embryo of the middle of the fourth month.
Outline of a photograph, enl. $^{12}/_{1}$.
C. ant., anterior commissure.
C.c., corpus callosum.
F., fornix.
F.c., fornix commissure.
I.H.T., interhemispherical tissue.
L. tr., lamina trapezoidea.
M.W., mesial wall of the pallium.
Str., striatum.
U., zone of union.
V., lateral ventricle.

In this brain the anterior commissure has a diameter of 0·6 mm. The more frontal part lies in the zone of union, the more posterior part in the lamina terminalis, covered from behind by the ependyma. It protrudes into the cavity of the third ventricle, a relation which is also often met with in the adult state. Large glia cells from the zone of union are spread between the various fasciculæ of the commissure. The corpus callosum lies entirely in front of the foramen of Monro, its posterior border agreeing exactly with the frontal border of the foramen. The tissue of the commissure is further histologically differentiated, having at this stage a more fibrous structure. This is also the case with the fornix. The fronto-occipital diameter of the callosum amounts to 2·4 mm. The most posterior part of it still lies in the lamina terminalis, but this relation is by no means so evident as it is in earlier stages of development. The lamina itself has become thicker, attaining now to a diameter of about 0·5 mm.

Fig. 4 gives the outlines of a section through the zone of union at the more posterior part of the callosum. The great commissure (C.c.) forms a closed system, which occupies the most dorsal part of this zone. On both sides the fibres of the commissure pass over into the mesial wall (M.W.) of the pallium in the same way as in the foregoing stage the fornix (F.) lies laterally of the callosum. The bundles of the fornix spread out as they pass over into the lamina trapezoidea (L. tr.). They may be followed in the section as far as the anterior commissure (C. ant.), when they bend sideways in crossing this system.

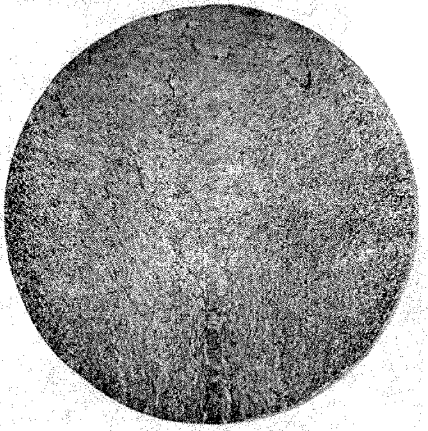


FIG 4A.

Photograph of that part of the section which is indicated by a black circle in fig. 4.
Photograph Zeiss obj. B.B., enl. $\frac{36}{1}$.

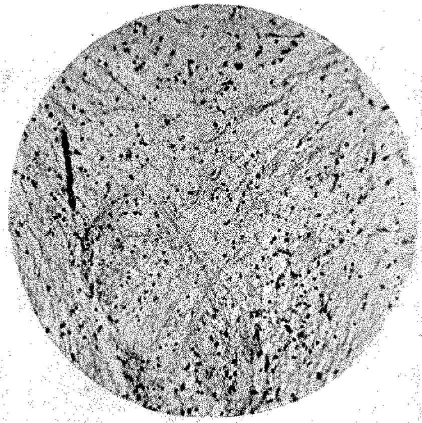


FIG. 4B.

Same section as fig. 4A; fornix commissure more strongly magnified.
Photograph Zeiss obj. D.D., enl. $\frac{70}{1}$.

At the angle where callosum and fornix meet, a bundle of fibres appears, coming from behind. This bundle spreads towards the median plane and crosses a bundle coming from the opposite direction. This crossing system belongs to the fornix, and represents the fornix commissure (F.c.). These relations may be illustrated by fig. 4A, which is the photographic reproduction of that part of the section that is indicated by a black circle in fig. 4; and by fig. 4B, which shows the structure of the fornix commissure more strongly magnified.

The crossing of the fornix fibres lies entirely in the zone of union, as the glia nuclei can be followed dorsally of this commissure and even in the adjacent layers of the callosum. The fronto-occipital diameter of the fornix commissure is 0·24 mm. In respect to the callosum, the fornix commissure is situated in such a way that the posterior border of the callosum exceeds the posterior border of the fornix commissure by 0·6 mm. Fig. 5 represents this relation diagrammatically.

In the region in front of the fornix commissure the callosum lies in the zone of union, whilst the fornix is confined to the mesial wall of the pallium and its continuation, the lamina trapezoidea. Only the most internal fibres of the fornix leave the wall of the pallium and pass through the glia tissue of the zone of union. From the relation I described between the callosum, the fornix and the fornix commissure, I should be inclined to conclude that the more posterior part of the corpus callosum in this stage of development already agrees with the splenium, as in the adult stage only this part of the commissure shows the same relation to the fornix commissure; it follows from the topographical relation of the more anterior part of the corpus callosum to the fornix bundles that this part of the large commissure agrees with the corpus and the genu of the callosum in the adult stage. Now, this view is further supported by the course of the fibres of the callosum. The more posterior fibres passing over into the mesial wall of the pallium bend in occipital direction, exactly in the same way as do the fibres from the splenium.

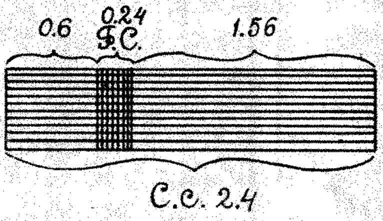


FIG. 5.

C.c., corpus callosum.
F.C., fornix commissure.

The same relation exhibits the more frontal fibres in respect to the frontal region of the brain, whilst the fibres of the middle part of the callosum have a more transverse direction. Moreover, the position of the fibres is such that in the posterior part of the callosum the fibres coming from more posterior regions lie nearer the surface than those coming from more anterior regions. Now the fibres, in proportion as they come from more occipital regions, have a more horizontal direction in the wall of the pallium, and this is the reason why in the preparations the frontal section of the callosum is triangular. The anterior part of the callosum shows a symmetrical condition in respect to the frontal region of the brain. In a schematic figure His [8] gives the same relations for a somewhat older embryo (fig. 93); only I have not been able to find the free ending fibres that His represents.

The zone of union of the pallia, in the frontal section, is triangularly shaped, with the base turned downwards (U, fig. 4). From above it is bordered by the callosum, laterally by the fornix bundles, and from below by the anterior commissure. It extends also a little below this commissure. This field is also triangular, the base resting against the commissure and the top turned towards the ependyma of the third ventricle. The tissue of which it is composed consists of glia cells. These cells are flat and mostly square or hexagonal. The nucleus is round and large and lies within a cell body that stains deeply with eosin. The cells form a meshwork with small meshes. The glia cells penetrate between the fibres of the callosum and also between the more internal bundles of the fornix. At the place where the anterior commissure passes through the zone of union they enter in large numbers into the substance of this commissure.

In the more posterior part of the zone of union, at the level of the commissure of the fornix, the structure of this tissue becomes loose in its middle portion (figs. 6 and 6A, l.p.). Here the nuclei are more distant, some of them are larger, and stain badly with hæmatoxylin; at the same time the meshes become larger. Adjacent to the fornix bundle the tissue is more dense (d.p.); the transitions between the looser and the denser parts are pretty abrupt. Now in my opinion we have here to deal with the beginning of a cleavage in the glia tissue as a rudiment of the cavum septi lucidi. The process extends in a fronto-occipital direction over a distance of 0·25 mm. As may be observed in the photographic reproduction (fig. 6A), the difference in the structure of the tissue does not give the impression of being artificial, because the shrinking of the tissue has only caused rents and fissures which are easily recognized. Independently of the mode of origin of the cavum, it is evident that the septum lucidum comprises more than the original mesial wall of the pallium, for the most internal fibres of the fornix pass through the glia tissue of the zone of union. The process of union of the two pallia does not differ in its general features from the process I described in the younger stage. Only the atrophy of the

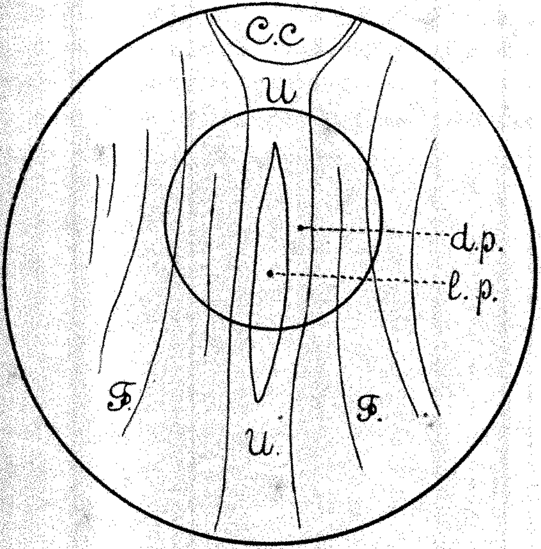


Fig. 6.

Frontal section through the more posterior part of the zone of union, at the level of the fornix commissure.

Human embryo of the middle of the fourth month. Outline of a photograph enl. $\frac{47}{1}$.

C.c., corpus callosum.
d.p., dense part of the glia tissue.
F., fornix.
l.p., loose part of the glia tissue.
U., zone of union.

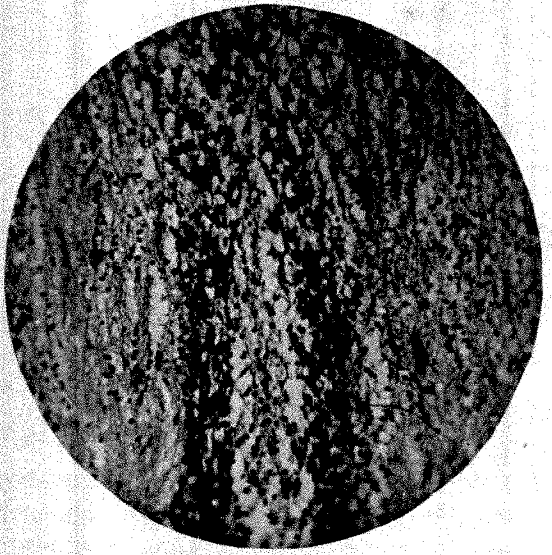


Fig. 6a.

Photograph of that part of the section which is indicated by a black circle in fig. 6. Zeiss obj. D.D., enl. $\frac{124}{1}$.

interhemispherical tissue and the ingrowth of capillaries coincide at several places and makes an analysis of the process illusory. At these spots at first sight a distinct line of demarcation between the interhemispherical tissue and the mesial wall seems to fail, but a close observation seldom fails to reveal some vestige of this line of demarcation. By the ingrowth of the capillaries the mesial wall gets, in the frontal section, a serrated appearance, and this causes distinct demarcation to disappear.

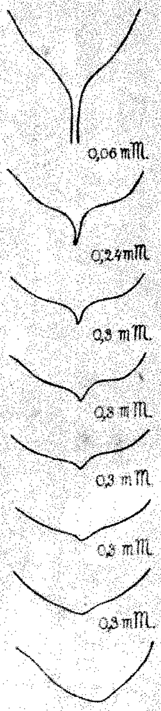


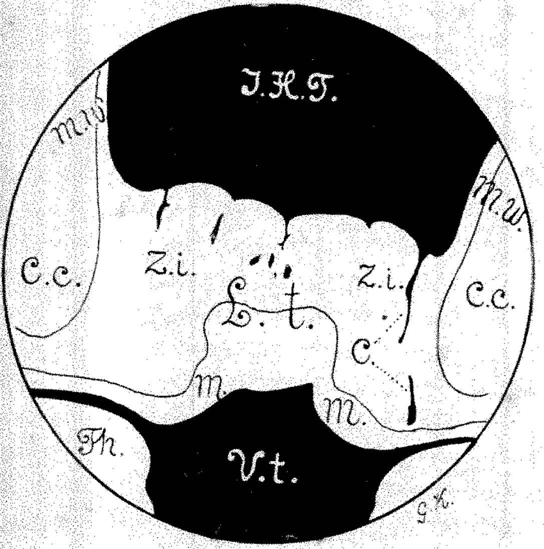
FIG. 7.

Successive profiles of the zone of union; the numbers indicate the fronto-occipital distance between the successive profiles.

Human embryo of the middle of the fourth month.

In the more frontal part of the zone of union the walls of the pallium meet at an acute angle, into which the interhemispherical tissue penetrates. The fibres of the callosum sharply bend round the top of the connective tissue. I have not seen any fibres ending free near the edge of the pallium wall in front of the zone of union. Going backward the notch between the two pallia gets more and more flattened and superficial (fig. 7). The fibres of the callosum show an equivalent relation and are still pressed against the notch.

From the combined observations I should be inclined to believe that the enlarging commissure pushes forward the interhemispherical tissue, and partially brings it to atrophy. The question often put forward, whether the union of the pallia takes place in consequence of the

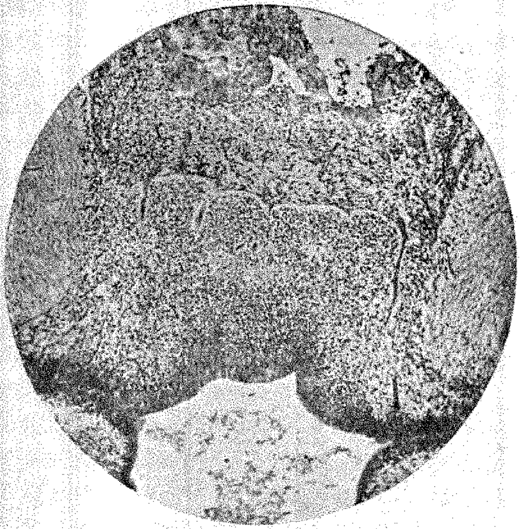


Frontal section through the lamina terminalis behind the corpus callosum.

Human embryo of the middle of the fourth month. Enl. $\frac{47}{1}$.

C., capillaries.
C.c., corpus callosum.
I.H.T., interhemispherical tissue.
L.t., lamina terminalis.
M., matrix.
M.W., mesial wall of the pallium.
Th., thalamus
V.t., third ventricle.
Z.i., intermediate zone.

FIG. 8



Frontal section through the lamina terminalis behind the corpus callosum.

Human embryo of the middle of the fourth month.

Photograph Zeiss obj. B.B., enl. $\frac{47}{1}$.

Fig. 8 is the outline of this photograph.

FIG. 8A.

protrusion of the lamina terminalis or otherwise by a more direct process, is a very subtle one; my preparations are not sufficient to enter upon this question.

Behind the corpus callosum the lamina terminalis (figs. 8 and 8A) is continued over a short distance (0·6 mm.). The posterior border of the lamina is folded in and goes over into the lamina choroidea of the third ventricle. It forms the roof of the foramen of Monro, and has no direct relation to the callosum. In its structure this part of the lamina agrees with the adjacent mesial wall of the pallium. The lamina consists of an ependymal layer turned towards the foramen of Monro, then a matrix (M.) and thereupon an intermediate layer (Z.i.). A distinct cortex and marginal zone do not seem to exist. The diameter of the lamina attains 0·44 mm. From the outside a large number of capillaries (C.) penetrate into the lamina, and this produces in a frontal section the curled appearance of the border of the lamina. This curling has therefore no direct relation to the process of union, as this part of the lamina terminalis never unites with any part of the mesial walls.

The structure of the mesial wall (figs. 9 and 9A) agrees with the description I have given of the younger stage, only the different layers are more clearly differentiated. At the place of inflexion and rupturing the mesial wall is most slender; towards the inferior border the wall increases in thickness, producing a club-like appearance in the frontal section. In this thickened part of the wall the callosum and fornix (C.F.) are situated.

Concerning the relations of the different layers, I have but little to add. In the more frontal region the cortex layer, at the level of the callosum, becomes looser and is continued into the cortex layer of the lamina trapezoidea. About the fore-edge of the zone of union, instead of loosening, the cortex layer becomes discontinuous, ending with a free, sharp edge (C.l.). At a single place, however, this edge is a little swollen, but in no case have I seen the protrusion of the surface of the pallium wall by the cortex layer. In this stage of development it may clearly be seen that the nuclei of the intermediate layer penetrate into the marginal zone (Z.m.n.) round the edge of the cortex layer, and cause this zone to disappear as a distinct layer. These nuclei are continued over the dorsal surface of the callosum. Also in this stage of development the commissure is strictly confined to the intermediate layer of the pallium wall; that this is really the case is clearly demonstrated by a section passing behind the foramen of Monro; there the under border of the pallium shows very distinctly a marginal zone, and nowhere fibres of the callosum are to be found piercing this zone and reaching the surface of the wall of the pallium.

In the same way as described for the posterior part of the lamina terminalis, the mesial wall is also curled by the ingrowth of capillaries from the interhemispherical tissue. In its structure this tissue does not differ from the description given in the younger stage, and I only wish to call attention to the abundance of large blood-sinuses in the connective tissue in this stage of development.

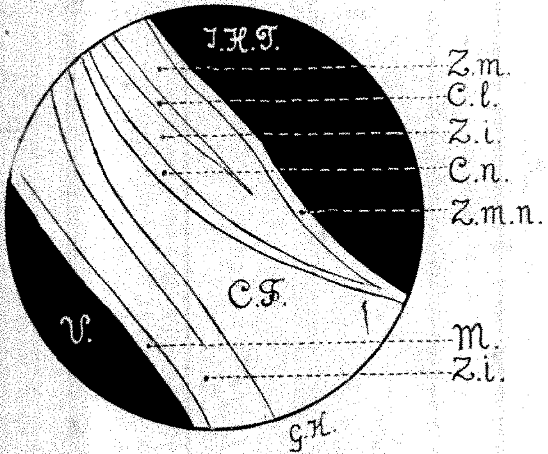


FIG. 9.

Frontal section through the mesial wall of the pallium at the place indicated by a circle (partly black, partly white) in fig. 4. The section from which the photograph is taken lies well behind the section of fig. 4. Enl. $\frac{36}{1}$.

C.F., corpus callosum and fornix.
C.l., cortex layer.
C.n., cap of nuclei surrounding the callosum fornix.
I.H.T., interhemispherical tissue.
M., matrix.
V., lateral ventricle.
Z.i., intermediate zone.
Z.m., marginal zone.
Z.m.n., nucleated part of the marginal zone.

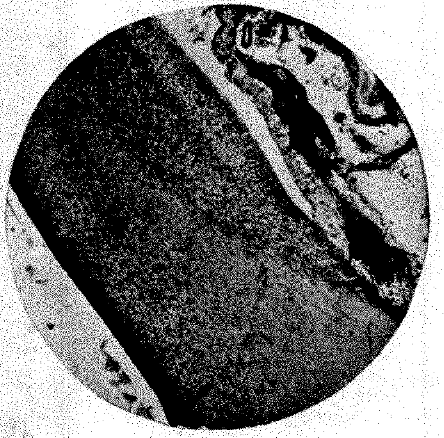


FIG. 9A.

Photograph of the mesial wall of the pallium; fig. 9 is the outline of this figure. Photograph Zeiss obj. BB, enl. $\frac{36}{1}$.

I have no material of the stage of development when the mesial walls begin to unite behind the foramen of Monro, so that for these later stages I can only add some superficial observations I gathered on inspection of median sections.

As a consequence of the enlargement of the corpus callosum the zone of union also increases. Dorsally of the foramen of Monro the posterior border of the callosum expands in an occipital direction and causes the mesial walls of the pallium behind the foramen to unite. At the same time with the enlargement, the callosum and the fornix bundle diverge, forming together a **V** lying on its side with the top turned backward. In frontal direction as well the callosum enlarges, forming the rostrum; under the influence of the expansion of the commissure in this direction the zone of union also increases. In the relative position of the systems of fibres no changes occur. The fornix bundle remains in a position lateral to the callosum in the reconstructed mesial wall of the pallium; the fornix commissure still lies ventrally of the callosum in the glia tissue of the zone of union. This latter relation is clearly seen in fig. 10, which is the reproduction of a drawing made of the median section of a brain of the end of the fifth month. Here the postero-inferior border of the callosum goes over into a beak, which is prolonged into a lamina (L.i.f.) that unites the two fornix bundles. In the beaked prolongation and adjacent to the callosum lies the fornix commissure (C.f.). If a frontal section were made at an appropriate level, this section would show the same relations as the sections reproduced in fig. 4, with the sole difference that a continuation of the cavum septi extends between the two commissures. The cavum septi, once formed, enlarges in a frontal as well as in an occipital direction, in correspondence with the enlargement of the callosum. On both sides of the median plane the posterior part of the cavum septi shows a protusion laterally of, and underneath, the callosum (R.pl.). In the same way as this recessus postero-lateralis there is a recessus antero-lateralis (R.a.l.), but this niche is by no means so well developed as the posterior one.

Now, from the fact that the fibres which compose the callosum show a regular arrangement in respect to the regions of the pallium they connect, it is obvious that the development of the pallium influences the form of the callosum. This is shown by the form of the splenium, which at the stage of development shown in the drawing is not yet rolled in. The rolling in of the splenium seems to be caused by the further differentiation of the lobus occipito-temporalis, to which the larger number of the fibres of the splenium belong. Now, the splenium follows the temporal lobe when bending round the thalamus in frontal direction, and consequently is rolled in. By the rolling in of the splenium, callosum and fornix bundle approach each other, so that the posterior part of the cavum septi becomes smaller and the recessus postero-lateralis is reduced to a transverse slit. The posterior narrowest part of the cavum—the ventriculus Vergæ—in most cases in the new-born still communicates with the anterior part of the cavum septi.

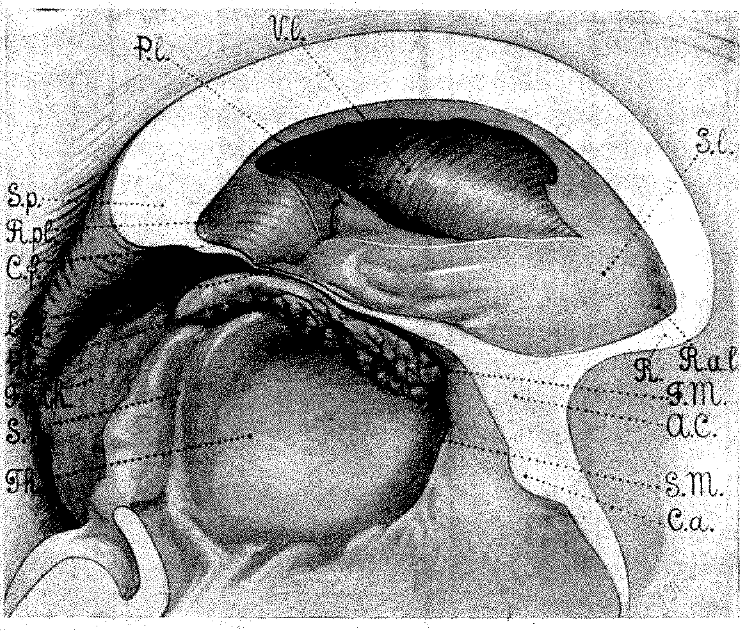


FIG. 10.

Drawing of the median section of a brain of the end of the fifth month, enl. $\frac{3}{1}$.
A.C., anterior part of the zone of union.
C.a., anterior commissure.
C.f., fornix commissure.
F.M., foramen of Monro.
F.p.th., posterior surface of the thalamus.
L.i.f., lamina interfornicaria.
P.l., choroid plexus of the lateral ventricle.
P.t., choroid plexus of the third ventricle.
R., rostrum.
R.a.l., antero-lateral recesses.
R.pl., postero-lateral recesses.
S.h., sulcus habenularis.
S.l., septum lucidum.
S.M., sulcus of Monro.
S.p., splenium.
Th., thalamus, mesial surface.
V.l., lateral ventricle.

From these stages of development as reproduced in the drawing it seems evident that the lamina that unites the two fornix bundles (L.i.f.)[1] is a remainder of the zone of union, for this lamina in frontal direction continuously goes over into the anterior part of this zone (A.C.), in which the commissura anterior (C.a.) is situated. Occipitally the lamina is continued in the prolongation in which the fornix commissure is located, and this tissue is also doubtlessly a remainder of the posterior part of the zone of union. The uniting lamina between the two fornix bundles in the adult stage shows exactly the same relation, only these parts of the zone of union into which it is continued are more reduced. Therefore this lamina, for which I should propose the name of "lamina interfornicaria," belongs neither to the corpus callosum nor to the fornix bundle, but is a remnant of the zone of union. Consequently the union of the fornix bundles in the median plane is a secondary one, and this explains, I believe, the relation that the lamina interfornicaria shows in respect to the fibres of the alveus, a connection to which Dejerine [3 (p. 278)] has given much attention.

SUMMARY.

(1) The anterior commissure precedes in its histological differentiation the corpus callosum and the fornix commissure.

(2) In a stage of development in which the diameter of the corpus callosum amounts to but 0·5 mm., about one-third of the commissure lies in the lamina terminalis and two-thirds in the zone of union.[2]

(3) From the relation of the corpus callosum to the fornix and to the fornix commissure it follows that the callosum at its first appearance shows all the essential features of the commissure in the adult stage.

(4) The interhemispherical tissue atrophies before the enlarging commissure.

(5) The true histological nature of the process of union of the walls of the pallium I must leave undetermined.

(6) The corpus callosum remains strictly confined to the intermediate layer of the wall of the pallium.

(7) In the region of the callosum the cortex layer of the mesial wall ends in a sharp edge.

(8) The cavum septi lucidi is probably formed by a cleavage in the glial tissue of the zone of union.

(9) The lamina interfornicaria is a derivative of the zone of union.

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[1] This structure is described by Marchand [15] under the name of "Bodenlamelle des Cavum septi"; by Martin [16] as "Verlängerte Schlussplatte"; and by Dejerine [3] as the "lamina intertrigonalis."

[2] Unless we consider the zone of union a direct derivative of the lamina terminalis, this result is partly in contradiction with the explicit statement of Elliot Smith in "Morphology of the True Limbic Lobe." [25 (p. 198)].

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THE STATE OF THE BRAIN DURING HYPNOSIS.

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THE attempt to formulate a theory of the hypnotic state has been approached by two very different roads. On the one hand there is the road along which the late F. W. H. Myers so brilliantly led the attack. Those who follow this road fix their attention on the most strange and perplexing of the phenomena of hypnotism; they seek to exhibit the gulf between the normal and the hypnotic states as very wide; they incline to regard the hypnotic condition as essentially one of extended faculty and increased mental power; and they value hypnotic experiment as one way of approaching the study of alleged supernormal and marvellous phenomena, belief in which orthodox science regards as a delusion bred by erroneous observation and engendered by an incorrigible yearning after empirical evidence of a realm of purely psychical existence.

The other more sober way in which the task of explaining hypnotic phenomena may be approached is to concentrate attention upon the simplest and least astonishing of them, to seek out and establish the affinities of hypnosis with better-known mental states, and to try to find some hypothesis that will account for these simpler facts and will bring our knowledge of hypnosis into line with the facts of our normal mental life and with theories that have proved their value in other departments of research; for, if any such working hypothesis can be formulated, it may be hoped that its field of application may be gradually enlarged and that the more perplexing phenomena may be brought within its range as our knowledge of them increases.

Though I would not disparage or undervalue speculations of the former kind, I believe that the second way of approach is more consistent with scientific principles, and the following pages present the results of my own gropings along this road.

The aim of this paper is to render a little clearer and more definite in detail a hypothesis which has been gradually taking shape during recent years under the hands of a number of writers, and which goes by the name of the *theory of cerebral dissociation*; for certain unorthodox views as to the nature of cerebral processes set out by me in former numbers of this Journal [6] and elsewhere seem to lend themselves very well to this purpose.

The current loose usage of the phrase "theory of dissociation" tends to the confusion of several different hypotheses which have little in common with one another, and some of which are held by authors who follow the former of the two roads distinguished above. There is the doctrine (or group of allied doctrines) which teaches that each normal personality comprises two selves, two personalities or strata of personality, which normally are in some sense fused together—the waking and the subwaking selves of Boris Sidis [9], the *Doppel-Ich* of Max Dessoir [2], the waking consciousness and the dream-consciousness, the primary and secondary personalities, of other authors [1]; and that mental dissociation somehow consists in the freeing of the lower, or normally submerged and hidden, stratum from the dominance and control of the upper stratum. I do not think that at the present time we are compelled to make, or are justified in making, the assumption that the normal human mind comprises any such submerged and coherent system of faculties as is implied by each and all of these allied doctrines.

More nearly allied to the form of the theory of dissociation that I am concerned to support is Pierre Janet's doctrine of mental disaggregation [4]. Janet speculates only in terms of psychical material, and refuses to attempt a corresponding neurological hypothesis; but I am very decidedly of the opinion that here, if anywhere, attempts at purely psychological explanation are out of place. I believe that any explanation or theory of the hypnotic state and phenomena must be psycho-physiological; for it seems clear that, during hypnosis, the brain is in some abnormal condition and functions in some manner different from that of the normal waking state, and that therefore we cannot claim to understand hypnosis until we learn the nature of this abnormal brain state; that, in short, a description of the abnormal state of the brain must be an essential, if not the essential, feature of any explanation of the facts.

Th. Lipps [5], of Munich, also has proposed an explanation which, although he states it in terms of psychical dispositions only, and so limits its usefulness, seems to me very helpful; and it can easily be translated into terms of psycho-physical dispositions and developed on those lines.

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[1] Possibly the doctrine of the Sublimal Self, elaborated by the late F. W. H. Myers, belongs to this group of theories, but I do not feel myself competent to class it.

Lastly, I would mention the speculations of Oscar Vogt [3] (accepted and endorsed by Forel) as those with which my own views, although independently reached, have the closest affinity.

It is held by many authors, notably by Bernheim—rightly, I think—that hypnosis is a state closely allied in many respects to normal sleep, although it presents important differences. The onset of the two states is very similar in many (if not all) cases, and it is favoured in both cases by the same influences and conditions, namely, by the withdrawal of all strong sense-stimuli, by restful position, by monotonous gentle stimulation of one or more of the senses, by expectation and habit, and by the banishment of exciting thoughts and the concentration of attention on some unexciting object or sense-impression.

Another point of similarity of the onset of the two states is the heaviness of the eyelids, which is generally the first symptom of both sleep and hypnosis, and which, in both cases, is generally accompanied by a general drowsiness and disinclination to make any effort or movement.[1]

In both states the subject lies inert and passive; his mind is less responsive than during the waking state to most of the sense-impressions from the outer world; and, although it is not completely shut off from their influence, it is apt to interpret them falsely. In both states the subject may entertain the most fantastic ideas, ideas absolutely incompatible with his actual situation or his best-established convictions, without recognizing their absurdity; and such ideas are apt to undergo some fantastic elaboration in keeping with any prevalent emotion; in both cases these ideational processes are characterized by a lack of the voluntary and critical control which is habitual and normal in the waking state. In both cases the subject not infrequently desires to move his limbs, but finds himself incapable of doing so. In both cases, again, the subject is very apt to have, when awakened, no spontaneous recollection of the ideas of the period (of sleep or hypnosis), though recollection can generally be evoked by appropriate questioning. Some subjects may be induced to display an abnormal suggestibility during normal sleep, and in some the cataleptic plasticity of the limbs, which is a so frequent symptom of hypnosis, may be induced during normal sleep.

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[1] I am, of course, aware that some subjects exhibit while in hypnosis a degree of liveliness and excitability apparently greater than the normal, and that some of their faculties may seem even more alert and active than during their normal waking life. But these are distinctly exceptional cases, and usually, I think, this lively state is only arrived at after some training. We have to concentrate our attention on the more usual type of hypnosis; for the symptoms of the state are so bewilderingly diverse and numerous that, if we attempt to form a theory which shall account at once equally well for all of them, it is obvious we shall fail. Very much depends upon the handling of each case by the operator. In my own experience I have generally aimed at inducing a sleep-like condition, and have always obtained this result, except where I have failed to induce any degree of hypnosis.

Lastly, if the subject in hypnosis is left to himself, he is apt to pass spontaneously into normal sleep, the transition from the one state to the other being perfectly gradual, so that no line can be drawn between them; and, conversely, the state of normal sleep may be converted into hypnosis.

The resemblance between hypnosis and sleep is, in some respects, still closer in the case of ordinary sleep-walking or somnambulism, which may perhaps be regarded as a state intermediate in character to these two.

On the other hand, hypnosis differs from normal sleep in that it has certain positive characteristics that are not found in the latter. A large proportion of these may be summed up by saying that the subject remains peculiarly sensitive to the influence of the hypnotizer, and that ideas introduced to his mind by the hypnotizer operate with unusual energy and effectiveness, or, as we say, the subject in hypnosis is very suggestible towards the operator, or readily takes suggestions from him.

The obvious line of approach is, then, to find a good working hypothesis as to the state of the brain in normal sleep; and, having formulated this, to try to understand what further peculiarities of the state of the brain are connected with the positive features in which hypnosis differs from sleep.

Unfortunately we have as yet no generally accepted theory of sleep. We have a number of partial theories or views—the view that sleep is due to the action of waste products of metabolism on the nervous tissue; the view that it is due to cerebral anæmia; the view that it is due to auto-suggestion; the recent view of Claparède [1] that the onset of sleep is an instinctive process.

There is probably some truth in all of these views, as well as in others; but neither individually nor collectively do they give an answer to the essential question: How does the state of the nervous tissue of the brain during sleep differ from its state during waking life?

It seems clear that during sleep the nervous substance of the cerebral hemispheres is either less excitable than during waking life or transmits any excitement less readily from part to part; and in all probability both these statements are true. A high degree of excitability and great freedom of transmission of excitement between all parts —these seem to be the essential positive characters of the waking brain that are lacking to the sleeping brain. Our definition of the state of the brain during sleep must, then, be a negative definition; it must consist in denying it the condition which underlies this proneness to activity characteristic of the waking state.

What, then, is this peculiarity of the waking state? The clue to the answer to this question is given, I think, by those rare cases of very widespread anæsthesia, of which the most striking and most frequently cited example is the case described by Strümpell [10]. The patient was a boy completely anæsthetic as regards all his sense-organs and sensory surfaces, with the exception of one eye and one ear. Whenever the sound eye was closed and the sound ear stopped, this patient fell almost immediately into deep sleep, and could then only be wakened by flashing a light into the sound eye or shouting into the sound ear, or otherwise stimulating violently one or both of these organs. That is to say, in this case the waking state was maintained only by the constant incidence of impressions on these sense-organs.

Now, it seems in the highest degree probable that the constant rain of stimuli upon our sense-organs plays a similar part in maintaining the waking state of the normal man; but the fact is obscured in two ways: firstly, by the great variety and sensitivity of the sense-organs of the normal man and the impossibility of shielding all of them from stimulalation; secondly, by what may be called the capacity of the human psycho-physical organism for maintaining an endogenous excitation. We must briefly consider these in turn.

Even if one lies still on a soft bed in a quiet dark place, the nervous system is yet liable to receive many stimuli, especially through the sense-organs of the kinæsthetic and visceral systems. Under these conditions we often become aware of these impressions, and often they excite some sense of discomfort, some need of movement or change, so that one may be kept turning restlessly without sleep. The most striking example of the power of these vague sense-impressions arising within the body to prevent sleep is afforded by those which excite the sensation of hunger.

Nevertheless, save in conditions of great fatigue, the withdrawal of stimuli from the principal sense-organs is a favourable and, for most of us, an essential condition of the onset of sleep. When sleep comes, its continuance depends upon the absence of strong sense-impressions; it may normally be terminated at any time by a sufficiently strong sensory stimulus, or by the summation of effects of a series of sensory stimuli, each of which is too weak to produce any marked change of state;[1] and even after sleep is thus banished we do not usually feel ourselves to be fully awake and alert until a further stream of stimuli has impinged upon our sense-organs.

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[1] I have described and discussed this process in some detail in the pages of *Mind* [7].

Now, unfortunately, our knowledge of the immediate effect of stimulation of a sensory nerve is still very imperfect; but there is much to be said for the view that the immediate and essential effect is a katabolic process which liberates chemically stored energy in the substance of the neurone, and that the spread of excitation consists in the discharge of this freed nervous energy from neurone to neurone across the synapses or places of junction of the neurones.[1] This distinction between chemically stored or potential nervous energy and the liberated active nervous energy is, I feel sure, one of the first importance for neurological speculation, although but little attention is commonly paid to it. Oscar Vogt has recognized its importance and has proposed to mark it by calling the freed nervous energy "neurokyme." Some years ago I, in ignorance of Vogt's work, proposed to call it "neurin." What name we use does not much matter, so long as we hold fast to this distinction and to this conception of liberated active nervous energy; but for this purpose some name is essential; since Vogt's proposal was prior to my own, and since my proposed name is so similar to neurine, the name of one of the chemical compounds found by the chemists in nervous tissue, I adopt Vogt's term "neurokyme" in place of "neurin."

During waking life, then, stimuli rain unceasingly on all the sense-organs and liberate in all the sensory nerves streams of neurokyme, which ascend by the sensory tracts of the cord and lower brain to the cerebellum and cerebrum. The brain is thus fed and its activity is sustained by these streams of energy, which keep it charged with neurokyme at a varying tension or potential; and this charge of free energy is constantly being worked off by thought or mental activity of any kind, for all mental activity involves the discharge of neurokyme from the sensory to the motor side of the brain, in accordance with James's law of forward conduction.

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[1] Some arguments in support of this view are adduced in two papers in former numbers of this Journal [6]. In a recent paper, privately printed (*Proceedings of the Junior Scientific Society*, Oxford), I have ventured to suggest that this way of conceiving the immediate effect of a stimulus upon a nerve affords a possible explanation of the fact that the amount of nervous response varies with the intensity of the stimulus applied. We may suppose that the katabolic change propagates itself along the substance of a neurone on the all-or-nothing principle, to which an explosive decomposition may be expected to conform; but we may suppose that the quantity of such change in unit of time varies with the energy of the incident stimulus, as in the case of a train of damp gunpowder. The distance through which the change will propagate itself, or, in other words, the length of nerve fibre, and hence the amount of nervous substance which undergoes the katabolic change, will, then, vary with the intensity of the stimulus; and since the quantity of energy liberated will vary with the amount of nervous substance which undergoes this change, it also will vary with the intensity of the stimulus. A maximal stimulus will, then, cause the katabolic process to propagate itself throughout the whole substance of the neurone, and every submaximal stimulus will cause it to propagate itself through a part only of the neurone substance, the length of which part will be proportional to the intensity of the stimulus. I throw out this suggestion with the greatest diffidence for the consideration of those who are better qualified than myself to say whether it is a tenable hypothesis.

Now consider the second condition that obscures the importance of sense-stimuli for the maintenance of the waking state—what was called above the capacity for endogenous or automatic maintenance of the state of excitation.

The organism comprises certain hereditary pyscho-physical dispositions, which, in the evolutionary sense, are essentially continuous with, or to be identified with, the instincts of the animals. In what each such disposition exactly consists we do not yet know, though no doubt an essential feature of it is a complex system of sensori-motor arcs. In the present connexion the important fact is that each such disposition is a great spring of nervous energy; when anyone is excited in any way. it liberates a great quantity of neurokyme that raises the activity of the brain to a higher level, a fact which manifests itself in symptoms of general excitement, in very energetic thought and action and, subjectively, in the form of impulse, desire, and emotion.

These dispositions can be excited by way of sense-presentation; hence sense-impressions contribute to the maintenance of the state of general excitation of the brain, not only in proportion to the intensity of the stimuli and the extent of sensory surface affected, but also in proportion as they lead to the excitement of any of these special springs of energy. In most of the animals these dispositions can be excited only by sense-impressions, but in the human being they can be excited also by way of representative or ideational processes. Hence the human mind and brain do not necessarily come to rest as soon as all sensory stimuli are withdrawn; the activity of an excitable brain may continue to be sustained by this process of endogenous liberation of energy, by the power of the impulses awakened through ideas and recollections. When this is the case, sleep can only be secured by the avoidance of emotionally exciting ideas, *i.e.*, by turning the attention to indifferent things—to sheep jumping through a gap in a hedge, to counting, or to some faint bodily impression.

The presence in the brain-neurones of a store of free energy or neurokyme derived from these two sources is, then, a prime condition of the waking state; but there is a second important condition, dependent in large measure upon this one, which underlies the freedom of transmission of excitation from point to point of the brain, the free interplay of all parts of the brain, that is characteristic of the waking state; this is the state of the synapses.

We can confidently infer that the neurones that make up the nervous tissue of the cerebrum are connected together to form functional groups, the members of each group being so intimately connected that excitement of any one member of the group tends to spread at once throughout the group to every member of it.

Such a group of neurones is a functional unit, and we may call it a psycho-physical disposition; of such groups the hereditary dispositions mentioned above constitute a very important and peculiar class. We may infer also that these dispositions are connected with one another with various degrees of intimacy to form systems; these, again, with less degrees of intimacy to form larger systems; and these yet again with still less intimacy to form still larger systems; and so on, until we reach the most comprehensive system, which is the whole of the central nervous system.

Each disposition is an intricately woven chain of neurones making up a complex sensori-motor arc or system of arcs. All thought, all perceptual or ideational mental process, involves the perpetual shifting of the main nervous current from one disposition to another, at any one moment some one disposition being the main path of discharge of neurokyme from the sensory side of the brain, where it is constantly accumulating, to the motor side; and, while any one disposition thus predominantly active is the principal focus of excitation, those most intimately connected with it are in a state of subexcitement. When any one disposition thus becomes the main path of discharge, it is because, owing to a favourable conjunction of circumstances, it has become for the moment the path of least resistance from sensory to motor side of the brain. The discharge through any one disposition is the neural concomitant of the rise to consciousness of a corresponding presentation or idea; and the shifting of the main stream from one disposition to another is the neural concomitant of the play of ideas, of the succession of presentations at the focus of consciousness, which continues so long as we are awake.

An essential feature of the view I am expounding is that the various degrees of intimacy of connexion between neurones and between groups and systems of neurones are held to be functions of the synapses or junctions of neurones. If excitement spreads readily from one group to another, it is because the synapses on the path connecting those two groups present at that moment a low degree of resistance; if it spreads less readily to another group, it is because the synapses on this connecting path present a greater resistance. Now there are many good reasons for believing that the resistance presented by any synapse is not a fixed quantity, and that it is not only permanently diminished in some degree by repeated transmission of the excitation-process, but that it is a quantity which varies from moment to moment under a number of influences, of which the most important are fatigue of its own substance, chemical influences from the blood, and the charge or potential of charge of neurokyme in the neurones between which the synapse forms a junction. That is to say, it is maintained that each synapse (in the resting condition of the part) presents a certain normal degree of resistance which varies from synapse to synapse, and is in each case a fixed quantity (or one only slightly or slowly changeable) determined by heredity and the course of individual experience; but that this normal degree, to which the resistance of each synapse returns when the brain is at rest, is constantly liable to be modified by the influences named above, being raised by fatigue and anæsthetic drugs such as alcohol and chloroform, diminished by strychnine and tetanus-toxin and by the excitement of the neurones between which the synapse lies.

This last condition is the most important one in view of the problem in hand. I assume, and the assumption is not without positive evidence in its favour, that the resistance of the synapse falls as the potential of charge of neurokyme rises in both, or in either one, of the neurones between which it lies, and that it rises as this potential falls.

In the waking state, then, the hemispheres being constantly supplied with large quantities of neurokyme from the two sources indicated above, the main mass of its neurones is kept moderately charged with this free energy, the result of which is that all synapses, and therefore all connecting paths, are kept in a state of partially lowered resistance; and there is, therefore, a constant free interplay between all parts of the brain, the main current of energy shifting freely from one disposition to another and from one system to another, each disposition tending to draw to itself a maximal stream of energy, each competing with all the rest for the fullest share of energy according to the principle of drainage.

Now, when we lie down to sleep in a quiet dark place, we shut off as nearly as possible all stimuli from the sense-organs, and we divert our thoughts from all emotionally exciting topics. The supply of neurokyme to the brain is thus diminished, the charge present in, or banked up in, the neurones of the afferent side of the brain falls to a lower potential, and, consequently, the resistance of the synapses in general rises. When sleep ensues from great general fatigue, another factor probably plays the principal part, namely, the waste products of metabolism, which, accumulated in the blood and lymph that bathe the synapses, act upon them, like chloroform or alcohol, as poisons which diminish their metabolism and so raise their resistance. Also, in the production of the sleep that ensues from deficient energy of the heart's action or from diminished circulation of blood in the brain, however produced, this second factor probably plays a large part, the waste products being allowed to accumulate locally. In normal falling asleep these two conditions—the general accumulation of waste products in the blood and the general slowing of the circulation—coöperate with the diminution of supply of neurokyme to raise the resistances of the synapses of all parts of the brain.

This general raising of the synaptic resistances throws the whole brain into a condition of *relative dissociation* or functional dissociation; that is to say, the dispositions and systems of dispositions, as well as the neurones comprised within any one disposition, become in some degree functionally isolated or separated from one another. And this functional discontinuity will be most complete in the case of the least intimately connected systems, less complete between the more intimately connected dispositions of any one system, and least between the neurones that are united in one disposition; for the resistance of each synapse will be reduced to, or near to, its normal resting degree.

Normal sleep implies, then, a state of relative dissociation of the brain, and the many points of similarity noted above between sleep and hypnosis indicate that hypnosis also involves relative dissociation of the brain; on the other hand, some of the phenomena of hypnosis, to be noticed below, afford positive evidence that such dissociation obtains, and so confirm the indications afforded by the foregoing consideration of the general physiology of the brain and of sleep.

We have to inquire: How does the state of the brain during hypnosis differ from this state of general relative dissociation of normal sleep? The answer to this question suggests itself when we consider the way in which hypnosis is commonly induced. The onset of hypnosis is favoured by the influences which favour sleep (with the exception, possibly, of fatigue), namely rest and quiet (*i.e.*, the withdrawal of sensory stimuli), the slowing of the circulation, the banishment of emotionally exciting thoughts, and by the expectation of sleep. How expectation operates remains a very obscure problem, but it is clear, I think, that in neither case is it an essential factor. The important influences brought to bear in the induction of hypnosis, in addition to those which normally produce sleep, are: (1) monotonous stimulation of sense-organs, either continued (as by visual fixation of a bright point) or intermittent (as by passes); such monotonous stimulation is favourable also to the onset of normal sleep; (2) the personal contact of the hypnotizer, who, by speech, by verbal suggestions, and by manipulations, keeps the subject constantly aware of his presence.

The monotonous stimulation seems to aid in bringing the whole brain to a quiescent condition, by facilitating the continued direction of attention to an object or impression of an unexciting uninteresting character, and thereby preventing the free play of ideas which otherwise may maintain itself for a considerable period in the way noted above. In terms of neural process we may say that the monotonous stimulation tends to keep some one minor disposition or small system of dispositions in dominant activity, keeps open this one path of discharge, so that this one channel, constantly draining off from the sensory side of the brain the supply of neurokyme, depresses, or tends to prevent, the activity of all others.[1]

The personal contact of the operator contributes to produce the same result. His passes, his manipulations, his verbal suggestions, all serve to keep the idea of the operator present to the mind of the subject, to keep the subject's attention (no doubt an attention of low grade or potential) directed to the operator; *i.e.*, in terms of neural process, they serve to keep in a state of excitation one system of psycho-physical dispositions, the system whose activity underlies the presence to consciousness of all thought of the operator; or, again, they tend to keep the main current of nervous energy shifting from one disposition to another within this one system. In this way, while all the rest of the brain is allowed to sink into a state of quiescence and of relative dissociation similar to that which obtains in normal sleep, this one system is kept active and waking, so to speak. It thus serves as an open channel through which ideas can be introduced to, or evoked in, the mind of the subject, as a single focus of nervous activity in a quiescent brain, from which focus other parts of the brain may be brought into play. Any proposition made by the operator to the subject is then accepted uncritically and acted upon because accepted with belief—that is the essence of suggestion—whereas the subject is blind and deaf to impressions from all other persons and objects, except in so far as they are connected in his mind with the operator, *i.e.*, except in so far as they belong to the same system of ideas.

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[1] That inhibition within the nervous system is always and at all levels a process of drainage of energy from one path or system to another in virtue of the lower resistance presented by the inhibiting path is a view that, as I have tried to show in a previous paper (*Brain*, vol. xxvi.), is compatible with all the facts and seems to be the only tenable working hypothesis.

Now a leading feature of hypnosis is that ideas or propositions suggested by the hypnotizer not only are accepted, but, being accepted, operate with a quite unusual force or effectiveness in the mind and on the body of the subject. The state of the brain described above, the state of relative dissociation of all systems except the one, enables us to suggest an explanation of this feature also. In the normal waking state any proposition about any topic or object is received more or less critically, and is only accepted with conviction if it is not incompatible with the organized body of knowledge or belief about that topic or kind of object already established in the mind. Every idea, we may say, has to withstand or overcome the inhibiting tendencies of these other ideas connected with the same topic before it is fully accepted, before it can prevail stably and determine action in the way characteristic of belief. But in the state of relative dissociation, any idea introduced to the mind by the operator prevails stably and determines action—is, in fact, accepted with belief—just because the ideas which could check or weaken its operation are not aroused, are not brought to bear upon it in criticism, owing to the state of relative dissociation which renders all interplay of ideas more difficult, more sluggish, than in the waking state. Further, in the waking state not only contradictory ideas, but all ideas whatsoever that have any tendency to rise to consciousness at the moment, play a similar part, weakening to some extent the force with which the dominant idea at the focus of consciousness operates in the mind and on the body.[1] The refined experimental researches of G. E. Müller upon reproduction and association seem to have established this fact [8].

We may try to express these relations in physiological terms. We must remember that in the waking state of the brain all dispositions and systems of dispositions are in relation of reciprocal inhibition with one another, such that the activity of any one tends to inhibit the activity of every other; and we may fairly suppose that between dispositions whose activities underlie incompatible or contradictory ideas about any object, this relation of reciprocal inhibition is peculiarly intimate and direct.[1] All dispositions, then, compete with another, except those that form a harmonious system and tend to express themselves in some particular mode of coördinated bodily activity. In the waking state, then, the energy with which any idea tends to express itself, or realize itself through bodily action, is thus diminished by the competition of all other ideas that have any tendency to rise to consciousness; or, in neural terms, the energy with which any disposition functions is normally to some extent depressed by the competition of all other dispositions that are in any state of subexcitation, and especially of those of contradictory ideas. In hypnosis, on the other hand, this depressing, weakening influence, this partial inhibition, is abolished or diminished in virtue of, and in proportion to the degree of, relative dissociation or functional isolation of dispositions from one another. Hence, any idea suggested by the hypnotizer is not only accepted uncritically, but operates with greater force than any idea accepted with conviction in the waking state.

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[1] I am, of course, using the word idea to denote the whole psycho-physical system of activity which reveals itself in consciousness as a presentation.

The absence or diminution of all such inhibitory weakening and restraint, and the correlative concentration of all available neurokyme along the channels of one disposition, seem to be the principal factors to be taken into account when we seek to explain all the commonest and most easily produced results of hypnotic suggestion, namely, the illusions, positive hallucinations,[2] delusions, the control of the voluntary muscles and (to some extent) of the involuntary muscles and of the visceral processes, secretion, nutrition, and so forth. While, as Pierre Janet has suggested, cataleptic plasticity of the limbs may be equally well regarded as due to the functional isolation of the cerebral tracts by which the afferent impulses ascending from the organs of the "muscular sense" return to those motor elements of the cortex from which the same movements and positions of the same parts are voluntarily effected (in accordance with the principle of the upper motor circuits). The weakening or abolition of reflexes, which, I believe, occurs only in very deep stages of hypnosis, may be regarded as due to the dissociation having attained so great a degree as to affect the functional continuity of the neurones composing the reflex arc.

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[1] The hypothesis of inhibition by drainage seems to lend itself well to the explanation of this kind of inhibition, although, of course, it is not possible to apply it in detailed fashion. We may liken the relation between the dispositions of contradictory ideas to the relation (so brilliantly studied by Sherrington—*see* "Integrative Action of the Nervous System") obtaining between the reflex arcs innervating antagonistic muscle-groups; and this case is not only truly analogous, but is probably more than analogous, it is probably the simplest example of the same type of functional relation. Contradictory ideas about an object tend to issue in opposed systems of muscular activity.

[2] It is perhaps worth while to expound the application of the hypothesis to one of these cases a little more in detail. Take the case of induction of a positive hallucination. It is suggested to a subject that a blank card carries a photograph of some familiar building. Perhaps the subject says he can see no picture on the card. A few irregular lines drawn on the card will then often facilitate the induction of the hallucination, and on repetition of the suggestion the subject may then admit that he sees the picture, and may describe it in some detail, and may even continue to see it on the same card when awakened, without post-hypnotic suggestion to that effect having been given. The influence of the lines drawn on the card in facilitating the induction of the hallucination (which in this case approximates to the type of illusion rather than pure hallucination) is significant. There is good reason to believe that the lines, serving as *points de repère*, are worked up among the hallucinatory lines of the subject's picture. We may suppose that the verbal suggestion of the picture of the familiar object evoked, in the mind of the subject, an image or visual representation of the building, which, when he directs his gaze to the card, is projected upon the card with hallucinatory or sensory vividness. I have sometimes been able to follow this order of events—the formation of a visual representation of an object while the eyes are closed and the subsequent projection of this image, with increasing vividness and distinctness, when the subject is directed to open his eyes upon a card. The neural events we may conceive as follows: the rise to consciousness of the visual image results from the spread of excitation to the

To negative hallucinations, and to the execution of post-hypnotic suggestions by a subject who remains unaware of the nature of the suggestions given, these principles of explanation are not so easily applicable; that is to say, while cerebral dissociation is implied by them, the principle is not in itself adequate to shadow forth an explanation of them; some further principle is implied. But these processes are especially interesting from the present point of view because they prove, more clearly than any other of the phenomena, that some functional dissociation of the brain is really present. In both cases we have unmistakable evidence that some process goes on in the brain independently of, and without affecting or being involved in, the main stream of psycho-physical process. Such, for example, is the deliberate ignoring by the subject of an object of which he has been told that it is no longer present, for although he certainly does not perceive the object

corresponding visual disposition from the auditory disposition directly excited by the verbal suggestion. If the subject were in the normal state and directed his gaze to the card, the lines upon it would be seen for what they are and the image would fade from consciousness as the attention was diverted to these lines; that is to say the disposition concerned in the production of the image would cease to function, because the main stream of energy would be diverted to another and simpler disposition, that which subserves the appreciation of the lines drawn on the card. But in the hypnotic state, owing to the relative dissociation and quiescence of all parts of the brain, save the disposition concerned in the production of the image, and owing to the abnormal preponderance of the excitation of this disposition over all others, the sensory impulses initiated in the retina by the lines on the card and passing up to the brain are diverted from the channels they would normally follow and are led into this preponderantly excited disposition. This disposition thereupon receives its stimulus, not only from other parts of the cortex in the way characteristic of ideational process, but directly from the sensory nerve tract; and this direct reception of sensory impulses seems to be in all cases the condition of the perceptual character or sensory vividness of a presentation. This view of the process of induction of the hypnotic hallucination brings it into line with the "recurrent sense-impressions" which are apt to follow on prolonged work with the microscope, on some one kind of structure, or on other constantly repeated sense-impressions; and also with the pathological hallucinations that seem to arise from morbid irritability of some brain tract. For in all such cases the hallucination may be plausibly regarded as due to the diversion of sensory impulses from their normal channels and their attraction into the over-excited system or disposition.

in normal fashion, and is apparently not conscious of it, his neglect and active avoidance of it show that the object is in some sense recognized;[1] and when a post-hypnotic suggestion is executed after a given number of repetitions of some signal, the signals clearly have been in some sense counted; and yet the subject remains unconscious of them. It is the facts of this order that have led so many authors to postulate a co-consciousness, a secondary stream of consciousness split off from the primary consciousness and flowing independently of it; for the processes involved seem to be distinctly mental processes, such as normally involve consciousness. There is much to be said for that view, and also there are difficulties in the way of its acceptance. But, though we may leave the reality of such co-consciousness an open question, we are compelled by the facts of this order to believe that a complex and orderly sequence of nervous processes, dissociated from the main stream of brain activity, is involved in the execution of such tasks; the dissociation seems to circumscribe the independently operating systems.

Anæsthesia also affords good evidence of dissociation; the sensory areas concerned with the reception of afferent impulses from the anæsthetic part seem to be profoundly dissociated from the rest of the brain; though whether this neural dissociation suffices in itself to account for the anæsthesia, and whether we are justified in assuming, as Janet does, that the sensations of the anæsthetic limb exist, or occur, as isolated sensations or sensations of a slender stream of secondary consciousness—these are very obscure questions which also we may leave open, while we accept the anæsthesia as positive evidence that at some point in the sensory path from the anæsthetic organ, probably a point within the cortex of the brain, resistance is abnormally increased in the way which constitutes dissociation.

The discontinuity of the memory trains of the hypnotic and the waking states, which so commonly obtains, is another piece of direct evidence of the reality of dissociation; although here, as in the preceding cases, it remains a very obscure problem: how can verbal suggestion determine the position of the line of cleavage or dissociation that separates the two systems?

A few words may be ventured as to the bearing of the views set forth above on the therapeutic applications of hypnotic suggestion. If these views represent an approximation towards the truth, it follows that the therapeutic value of hypnotic suggestion consists principally in the fact that it is a means of concentrating powerful currents of nervous energy in any required direction and of withdrawing them from other parts. By thus withdrawing the nervous currents from an overworked or unduly irritable nervous centre or bodily organ, and by isolating it through induction of a relative dissociation of the centre, rest may be secured and a bad habit of over-action may be suspended, as, *e.g.*, in neuralgia; while, by repeatedly directing a powerful stream of innervation through some other channel, a too sluggish organ (*e.g.*, the bowel) may be brought back to a more active and healthy functioning, a habit that has become disordered or unduly weakened may be restored, or a new habit may be set up to supplant, counteract, or suppress some undesirable habit. Under these two heads, the increase or the diminution of the metabolism and functioning of organs, most of the therapeutic effects of hypnotic suggestion may, I think, be classified.

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[1] The subject usually avoids turning his gaze directly upon such a forbidden object.

There are a number of phenomena that remain very obscure, and it is not claimed that the theory of cerebral dissociation as here presented provides a complete explanation of any of the facts. But that cerebral dissociation of some degree is at least one of the essential features of the hypnotic state can, I think, hardly be doubted; and though it may be questioned by some whether even a complete account of the cerebral changes would afford anything like a complete explanation of the facts, it can hardly be disputed that any complete theory of hypnosis must take the cerebral changes into account. I venture to think that the foregoing hypothetical description of the state of the brain during hypnosis may render the conceptions of cerebral dissociation, of the peculiarity of the hypnotic dissociation, and of the process of its induction, a little clearer and more definite than they have hitherto been. It is but just to point out that the hypothesis of cerebral dissociation which I have endeavoured to develop seems to have been first suggested by Hughes Bennett,[1] and that therefore, if it should ever attain to the rank of a generally accepted theory, the credit of having first enunciated it must be assigned to him.

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[1] I am indebted to Dr. Milne Bramwell for having drawn my attention to this fact on the occasion when the substance of this paper was read to the Medical Society for the Study of Suggestive Therapeutics over which he presides. It would seem that the theory was first implied by Bennett in a lecture entitled "The Mesmeric Mania of 1851," delivered and published at Edinburgh in the year 1851. I have not been able to refer to a copy of this lecture.

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THE NATURE AND QUANTITY OF DISSOCIATION CHANGES PRODUCED IN SALINE SOLUTIONS BY KNOWN QUANTITIES OF ELECTRICITY.

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OWING to the fact that electro-chemical action has now assumed such a prominent position in the investigation and accurate definition of the minute topographical anatomy of the central nervous system, the following observations may prove of interest.

These investigations have been undertaken with the object, primarily, of estimating the quantities of alkali and acid which are produced in living brain tissue under the influence of electrolysis in the neighbourhood of the kathode and anode respectively as one of the residual products of electrolytic dissociation, brought about by means of feeble constant currents of known milliamperage.

Through the kindness of Sir Victor Horsley and Dr. R. H. Clarke, I have been present during many of their experiments, and subsequently had the opportunity of examining numerous microscopical sections of portions of brain substance, wherein minute lesions have been produced by electro-chemical means.

Although the kathodal lesion has been attributed mainly to the action of sodium hydroxyl, yet an examination of these lesions, both kathodal and anodal, affords striking presumptive evidence that in addition to mere chemical agencies a stronger and more potent factor is called into play in their production; for in every instance a marked mechanical element stands out pre-eminent. This mechanical factor is undoubtedly due to the pressure of the gases evolved during electrolysis, the effects of which are not alone dependent upon the volume and quality of such gases, but also upon the density of the current which has been responsible for their production.

A detailed description of these lesions is here superfluous, as they have been fully described in an article on this subject by Sir Victor Horsley and Dr. R. H. Clarke [1].

For the purpose of these investigations, however, there is one point upon which I desire to lay especial stress, namely, the fact that it is blood and blood-clot, and not actual brain tissue, which is invariably found in the immediate vicinity of the electrodes; and consequently it must of necessity be within this substance that the major portion of electro-chemical action takes place, although, as will be subsequently shown, the reaction is by no means confined to this area, for certain of the products of dissociation are undoubtedly disseminated through the tissues into which the gases evolved make their way.

The fact that alkali and acid are produced in brain tissue in the neighbourhood of the kathode and anode respectively under electrolysis is undoubted, and is but the natural outcome of electro-chemical laws. For brain substance may be regarded electro-chemically as a saline electrolyte, since it is but an aqueous jelly, holding immeshed in every part inorganic salts (derived from the blood and lymph); under the influence of electrolysis, therefore, it offers but little more resistance to the ionic migration of these substances than does a simple electrolytic solution of these salts to which Faraday's laws are applicable.

The presence of alkali and acid may be demonstrated on their production in brain tissue by bathing the neighbourhood of the kathode and anode with weak solutions of phenolphthalein and dimethylamido-azo-benzol; on closure of the current, gas is immediately evolved, and simultaneously the colour index, purple red and rose pink, appear at the kathode and anode as evidence of the presence of alkali and acid respectively. It is worthy of note that the purple red colour increases in intensity in proportion to the duration and strength of the current, and that it is chiefly conspicuous in the immediate vicinity of the electrode, but yet is in no way confined to this area, for it will be seen to spread rapidly in all directions in which the gas evolved may travel; this colour, therefore, may in many instances be seen upon the surface of the brain though the electrode is buried beneath its surface and not apparently connected therewith. But on closer examination it will be seen that minute bubbles of gas have permeated the brain substance, and even after so doing they retain the power of conveying with them an alkaline atmosphere, as is shown by this phenomenon.

This fact is important in proving the statement previously made that the products of electrolytic dissociation are not confined to the immediate vicinity of the electrode, but, on the contrary, are universally distributed over the area permeated by the gases evolved during electrolysis.

Similarly evolution of gas occurs at the anode, but in far less appreciable quantity than that evolved at the kathode. Almost simultaneously with its appearance will be seen a faint rose pink tinge at a minute distance from the electrode, showing, therefore, the formation of an acid; the colourless zone seen in the immediate vicinity of the electrode is due undoubtedly to the bleaching effect of the chlorine there liberated, which can be readily identified by its odour even at some little distance from the electrode. To this phenomenon allusion will be made when dealing with the quantitative estimation of acid, as compared to that of the alkali.

Having shown that acid and alkali are produced in brain tissue during electrolysis, it is of interest to trace the chief source of their origin. In this connection it is important to remember that the electrodes (as already stated) are surrounded by blood. It follows, therefore, of necessity that from the inorganic constituents of the serum (*vide* note 1) an acid and alkali must be produced as the outcome of its electrolytic dissociation.

Note 1.

Inorganic constituents in 1,000 grm. human blood-serum.[1]

Total inorganic material ...	8·57 grm
Potassium sulphate	0·283 grm.
Potassium chloride	0·362 grm.
Sodium chloride	5·591 grm.
Sodium phosphate	0·273 grm.
Soda	1·545 grm.
Calcium phosphate	0·300 grm.
Magnesium	0·220 grm.

From the above figures it is clearly evident that blood-serum is a highly ionized saline electrolytic solution, within which preponderates to a very marked degree the readily dissociable inorganic salt sodium chloride. Consequently, under the influence of electrolysis, of the many metallic radicals present, sodium is readily and freely liberated at the kathode, and, being incapable of individual existence in the presence of water, it reacts upon it to form sodium hydroxyl, liberating thereby an equivalent quantity of hydrogen.

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[1] C. Schmidt's estimation (*vide* Limbeck, "New Sydenham Society," 1901, vol. cxlvii., p. 87).

Similarly under these circumstances chlorine, which is the chief acid radical, is liberated at the anode, which, in its turn, reacts to a variable extent upon the water present, thereby setting free an equivalent quantity of oxygen, an acid being simultaneously produced.

With regard to the exact nature of the acid here formed, it is impossible to make any definite statement, owing to the numerous and complex subsidiary reactions which occur in chlorine dissociation, a fact which has been ably illustrated in the works of Förster and Müller.

It is, however, certain that during anodal dissociation of such an electrolyte, a concentration of hydrogen ions takes place in the neighbourhood of the electrode, a phenomenon which must contribute materially to the increased acidity which takes place during electrolysis.

It is also equally certain that though a minute quantity of chlorine escapes during electrolysis, yet a large proportion remains in the electrolyte, either free or in a loose chemical combination, as is shown by the marked bleaching propensities of the same long after electrolysis has ceased. It is possible, therefore, that some of this chlorine reacts upon the hydroxidion and hydrion present, with the production of hypochlorite and hydrochloric acid.

This hypothesis is further strengthened by the fact that the total volume of gases actually estimated at the anode varies considerably with the density of the current; and such hypothesis would likewise account for the marked divergence subsequently shown in the total volumes of the gases liberated at the anode and kathode respectively when examined under identical conditions.

It is most probable, however, that the acidity subsequently estimated in these experiments is due to the first-named causes, *e.g.*, concentration of the hydrogen ions and hypochlorite, for the acidity therein ascertained proved of a very unstable and evanescent quality. This was shown by bringing moistened blue litmus paper in contact with the electrode during electrolysis, when the vivid red border surrounding the central bleached area so produced faded rapidly if the paper was immediately removed from the solution and washed and immersed in pure distilled water; this phenomenon was not so readily obtainable when the paper had been touched, even with a very weak solution of hydrochloric acid.

In addition to these substances many acids and alkalies, organic and otherwise, and other complex bodies are produced as the outcome of electrolytic dissociation of blood; with these, however, I am not concerned, for my primary object is but to estimate approximately the total residual quantities of alkali and acid, the chief of which are in all probability those above specified.

With this object in view estimations were attempted in living brain tissue, portions of which were treated *in situ* within identical glass cylinders under precisely similar conditions. Such a method, however, proved totally inadequate, for though the conditions adopted were identical, the contents of these cylinders varied widely, and, consequently, neither comparative nor even approximate estimation could be made; and the investigation, for this reason, had to be relinquished.

Since, however, the electrodes in brain substance are intimately surrounded by blood, I have adopted—for the purpose of comparison and estimations—in the following experiments two saline electrolytic solutions, (A) and (B) (*vide* note 2), the one being but a simple 0·685 per cent. sodium chloride solution, the other a compound saline electrolytic solution similar in many respects to blood-serum in inorganic salts. By this means—for reasons subsequently shown—some approximate idea may be gained of the amounts of alkali and acid which are produced in brain substance under analogous (*i.e.*, electrolytic) conditions.

Note 2.

Solutions.

(A)	Sodium chloride	...	3·888	grm.
	Water (distilled)	...	568·340	c.c.

Thus = 0·685 sodium chloride solution.

(B)	Sodium chloride	...	3·24	grm.	3·888 grm.
	Sodium sulphate	...	0·162	,,	
	Sodium carbonate	...	0·162	,,	
	Sodium phosphate	...	0·1296	,,	
	Potassium chloride	...	0·1944	,,	
	Water (distilled)	...			568·340 c.c.

(Compare with note 1, blood-serum.)

50 c.c. (A) solution equivalent in alkalinity to 0·00008 grm. NaOH.
50 c.c. (B) solution equivalent in alkalinity to 0·0036 grm. NaOH.

(Though the above represents the average alkalinity of these solutions, they are subject to slight variation under atmospheric conditions, and were consequently examined prior to any series of experiments.)

In order to carry out the following estimations, I had made for me by Messrs. Müller and Co. the glass electrolytic apparatus shown in fig. 1, consisting essentially of two limbs connected by a narrow glass tube fitted with a stopcock. Each limb of the apparatus is capable of containing 50 c.c. of fluid and is graduated in cubic centimetres and $\frac{1}{10}$ c.c.,

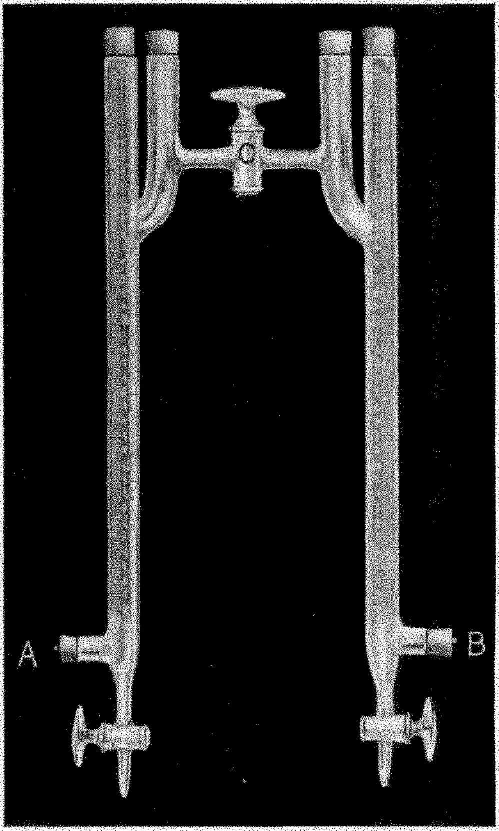

Fig. 1.
(One-third original size.)
A and B, platinum electrodes. C, stopcock.

and fitted with stopcocks and rubber corks through which insulated platinum electrodes are inserted.

By this arrangement mechanical disturbance in the fluids, due to the evolution of gases during electrolysis, is prevented, and no diffusion occurs between the products of dissociation at the anode and kathode.

In this respect the instrument proved accurate for estimations extending over periods of twenty minutes when using currents up to 5 ma. The simplicity of its construction permits of thorough cleansing of every part, the chief disadvantage being its high internal resistance, necessitating as it does a powerful battery of 12 volts to 15 volts to obtain currents of 4 ma., even in electrolytes so highly ionized as the solutions under estimation. (In a normal solution of sodium chloride at 18° C. a little over two-thirds of the salt is split up into its constituent ions.)

My first experiments were conducted with solutions (A) and (B), in order first to estimate the actual residual quantity of alkali which is formed in the two solutions by currents of known milliamperage; and secondly, by comparing the results thus obtained, to ascertain to what extent they were influenced by subsidiary reaction.

In order to make these estimations, the original alkalinity of the solution having been estimated, the apparatus was filled with one or other of the solutions to be examined, and then fixed rigidly so that no movement could take place; the stopcock, C, being opened, the solutions were then subjected to electrolysis, the current being regulated by means of a rheostat and measured by a galvanometer.

On completion of electrolysis the stopcock, C, was closed and the whole or part of the contents of either limb was withdrawn for examination. This was carried out by adding a known quantity of neutral litmus solution and titrating with $\frac{1}{100}$ N NaOH or H_2SO_4 solution, the end reaction being indicated by comparison with a standard colour.

$$1 \text{ c.c. NaOH } \tfrac{1}{100} \text{ N} = 0{\cdot}0004 \text{ grm. NaOH.}$$
$$1 \text{ c.c. } H_2SO_4 \tfrac{1}{100} \text{ N} = 0{\cdot}00049 \text{ grm. } H_2SO_4.$$

(Owing to the composition of solution (B) it must of necessity follow that in addition to the sodium hydrate and hydrochloric acid, other alkalies and acids are produced as the outcome of electrolysis. Consequently, throughout this article, wherever solution (B) was utilized the figures are but relative, signifying only that an amount of alkalinity or acidity was estimated which is equivalent to an amount of NaOH or H_2SO_4 which is shown by these figures.)

In order to attain my first object, namely, to ascertain the quantities of alkali which are produced in the solutions (A) and (B) under electrolysis, a series of twenty experiments was made, a current of 1 ma. being utilized for a period of ten minutes, the results of which experiments are shown in the following table:—

TABLE I.

Estimations with regard to the amount of Alkali which is produced in Solutions (A) and (B) under the influence of Electrolysis.

	50 c.c. of Electrolytic Solution. (A)			50 c. c. of Electrolytic Solution. (B)		
Conditions. Kathode.	Original alkaline equivalent of the electrolyte prior to electrolysis	*Estimated gain in alkalinity after electrolysis*	Such amount when reduced to terms of 1 ma × 5 m	Original alkaline equivalent of the electrolyte prior to electrolysis	*Estimated gain in alkalinity after electrolysis*	Such amount when reduced to terms of 1 ma. × 5 m.
	Grm. NaOH	Grm. NaOH	Grammes	Grm. NaOH	Grm. NaOH	Grammes
Same in both electrolytic solutions, namely, 50 c.c. of solution, 1 ma. current, 10 m. duration, 1 cm. electrode, 28 gauge S.W.G.	0·00008	**0·00026**	0·00013	0·0032	**0·00032**	0·00016
	0·00008	**0·00024**	0·00012	0·0032	**0·000213**	0·0001065
	0·00008	**0·00024**	0·00012	0·0032	**0·000266**	0·000133
	0·00008	**0·00028**	0·00014	0·0032	**0·00024**	0·00012
	0·00008	**0·00026**	0·00013	0·0032	**0·000266**	0·000133
	0·00012	**0·00024**	0·00012	0·00512	**0·00032**	0·00016
	0·00012	**0·00024**	0·00012	0·00512	**0·0002932**	0·0001466
	0·00012	**0·00024**	0·00012	0·00512	**0·00024**	0·00012
	0·00012	**0·00024**	0·00012	0·00512	**0·00024**	0·00012
	0·00012	**0·00024**	0·00012	0·00512	**0·000266**	0·000133
Total:		**0·00248**			**0·0026642**	

For purposes of comparison in the above and all subsequent experiments all estimations have been reduced to a common denomination, signified in the right-hand column of each series of experiments.

A review of the above figures definitely proves three points: First, that in both solutions an alkali is produced; secondly, that in both instances the amount is very small; and, thirdly, that the difference in the respective quantities is exceedingly minute.

It is seen that in solution (A) the total gain in alkali is equivalent to 0·00248 grm. NaOH, as against 0·0026642 grm. in (B), representing, therefore, a total difference of only 0·0001842 grm. in ten experiments extending over a period of ten minutes, or an average per estimation of 0·000248 grm. in (A), as against 0·00026642 grm. in (B), a difference of only 0·00001842 grm. NaOH in individual estimations.

These quantities are exceedingly small, although the period of electrolysis was of comparatively long duration. Now since it was my object to ascertain what amount of alkali is actually produced in brain tissue during the formation of the lesions above alluded to, I have still further reduced these amounts proportionately for currents of 1 ma.

acting for thirty seconds, which for reasons subsequently shown may be done by dividing these figures by 20 (*vide* Tables I. and IV.). By so doing we ascertain that 0·0000124 grm. NaOH is produced in (A), as against 0·000013321 grm. in (B), a difference therefore in each estimation of 0·000000921 grm. only NaOH in the two electrolytes under these conditions, which quantity may be looked upon as non-existent.

Since, therefore, this difference is practically inappreciable in two solutions varying so essentially from one another, though alike in their main inorganic content, NaCl, it is seen that subsidiary reaction may be disregarded, and, therefore, an approximate estimate may be gained of the amount of alkali which is formed in blood-serum under the influence of electrolysis; for there exists between it and solution (B) a marked similarity in inorganic content, and in both of them sodium chloride preponderates, from which substance the alkali is doubtless produced in brain tissue.

If such analogy be admitted the following experiments may be of service in giving some approximate idea of the amounts of alkali and acid which are produced in brain tissue under similar conditions; and also an insight with regard to certain other phenomena which contribute to the production of these lesions.

In the experiments enumerated under Table II. I have estimated the amount of alkali which was produced by means of currents of 2 ma. in solution (B) acting for periods of five, ten and twenty minutes.

TABLE II.

Estimations with regard to Duration of Electrolysis.

Current, 2 ma.; electrolytic solution (B).

Gain in NaOH in 5 minutes	Reduced to 1 ma. for 5 m.	*Gain in NaOH in 10 minutes*	Reduced to 1 ma. for 5 m.	*Gain in NaOH in 20 minutes*	Reduced to 1 ma. for 5 m.
0·00028	0·00014	**0·00052**	0·00013	**0·00104**	0·000125
0·00024	0·00012	**0·00052**	0·00013	**0·00116**	0·000145
0·00032	0·00016	**0·0004**	0·0001	**0·00128**	0·00016
0·00024	0·00012	**0·0006**	0·00015	**0·00124**	0·00013
0·00028	0·00014	**0·0006**	0·00015	**0·00116**	0·000145
Total: **0·00136**		**0·00264**		**0·00588**	

Results here obtained point to a definite proportional relation between the amount of alkali produced and the duration of the current, or as may be otherwise expressed, the amount of alkali is directly proportional to the amount of electricity which flows through the solution in a given time.

Under Table III. will be seen the results of experiments conducted with solution (B), under identical conditions as to time and milliamperage of the current, the only difference being the calibre of the electrodes.

Table III.

Estimations with regard to the Calibre of Electrodes.

(*Here synonymous with density of current.*)

Current, 2 ma.; duration ten minutes; electrolytic solution (B).

Gain in NaOH Electrode 1 mm. long Gauge $\frac{1}{16}$ mm.	Gain when reduced to 1 ma. for 5 minutes	*Gain in NaOH Electrode 2 mm. long Gauge $\frac{1}{16}$ mm.*	Gain when reduced to 1 ma. for 5 minutes	*Gain in NaOH Electrode ½ cm. long Gauge 23 S. W. G.*	Gain when reduced to 1 ma. for 5 minutes	*Gain in NaOH Electrode 1 cm. long Gauge 23 S. W. G.*	Gain when reduced to 1 ma. for 5 minutes
0·00064	0·00016	**0·00052**	0·00013	**0·0006932**	0·0001733	**0·00048**	0·00012
0·0004264	0·0001066	**0 0006**	0·00015	**0·000532**	0·000133	**0·000532**	0·000133
0·000532	0·000133	**0·0006**	0·00015	**0 00048**	0·00012	**0·000532**	0·000133
0·000532	0·000133	**0·0006**	0·00015	**0·0004264**	0·0001066	**0·000672**	0·000168
0·000532	0 000133	**0·00052**	0·00013	**0·00048**	0 00012	**0·000532**	0·000133
0·00064	0·00016	**0·0006**	0·00015	**0·0006932**	0·0001733	**0·00064**	0·00016
0·0005864	0·0001466	**0·00052**	0·00013	**0·000672**	0·000168	**0·000782**	0·0001955
0·0005864	0·0001466	**0·0006**	0·00013	**0·00052**	0·00013	**0·00048**	0·00012
Total: **0 0044752**		**0 00456**		**0·0045368**		**0·00465**	

Seeing that the currents, time and solutions are identical, the above experiments may be regarded as an estimation wherein the density of the current is examined, with regard to its effect upon the quantities of alkali produced.

These figures show that no virtual difference is appreciable in the residual amounts of alkali, though such estimations have been made with electrodes varying markedly in size. Consequently, the density of the current does not virtually affect the amount of alkali produced provided the quantity of electricity be the same. (*Compare* Table VI.)

The next investigations were conducted in order to ascertain to what extent the quantities of alkali produced were influenced by the milliamperage of the current in any given time, namely, currents of 1 ma., 2 ma. and 4 ma.

TABLE IV.

Estimations with regard to the Milliamperage of Currents of 1 ma., 2 ma. and 4 ma. acting for a period of ten minutes in Solution (A).

(*Herein synonymous with Quantity of Electricity.*)

Duration, ten minutes; electrolytic solution (A).

Gain in NaOH Current 1 ma.	Gain when reduced to 1 ma. for 5 minutes.	*Gain in NaOH Current 2 ma.*	Gain when reduced to 1 ma. for 5 minutes.	*Gain in NaOH Current 4 ma.*	Gain when reduced to 1 ma. for 5 minutes
0·00024	0·00012	**0·00052**	0·00013	**0·00092**	0·000115
0·00024	0·00012	**0·00048**	0·00012	**0·001**	0·000125
0·00024	0·00012	**0·00048**	0·00012	**0·001**	0·000125
0·00024	0·00012	**0·00048**	0·00012	**0·00112**	0·00014
0·00024	0·00012	**0·00052**	0·00013	**0·00084**	0·000105
Total: **0·0012**		**0·00248**		**0·00488**	

For these experiments solution (A) was selected in preference to solution (B), since previous experiments proved that the delicacy of the end reaction was more apparent, and the results thus obtained more constant (*vide* Table I.); a fact which may be attributed to the simplicity of its composition, and its faint original alkalinity.

Fifty cubic centimetres of solution (A) represented prior to estimations an alkalinity equivalent to 0·00012 grm. NaOH, the electrode used being 1 cm. of platinum 23 Imperial Standard Wire Gauge.

It will be seen that a very definite proportional relation is established between the amount of alkali produced and milliamperage of the current in a given time.

A survey of the above Tables I. to IV. proves that the resultant product of electrolytic dissociation of these electrolytes—in so far as the alkali—is virtually dependent upon the amount of electricity which flows through them, and upon no other factor.

That this relative proportionality is maintained throughout the whole series of these experiments is quite apparent, for the results, in so far as the alkali produced, are almost invariably alike; it does not matter whether currents of high or low density be used, or whether 2 ma. for five minutes or 1 ma. for ten minutes be utilized, the results are virtually the same. From this fact it may be assumed that the slight variation in the two solutions, as regards the amount of alkali produced, is not so materially due to the quantity or quality of electricity which has been utilized as to the original nature of their composition, and that subsidiary reaction apparently in no way influences the results.

With regard to the estimation of the acid I was unable to obtain the same definite results, this being, I consider, chiefly accounted for by interference with the delicacy of the indicator, owing to the bleaching effect of the chlorine in solution after electrolysis.

This difficulty was in a measure overcome by adding to the content of the anodal chamber, prior to titration, a known and sufficient quantity of $\frac{1}{100}$ N NaOH, in order to make the solution alkaline, thus combining any free chlorine present. The solution was then titrated against a known quantity of $\frac{1}{100}$ N acid solution, allowance being made in the estimations for the previous alkalinity of the solution, together with the quantity of alkali added subsequent to electrolysis.

The following Table V. shows the results obtained in five simultaneous estimations of the respective amounts of acid and alkali produced in solution (A) under the influence of currents of 2 ma. of ten minutes duration, the results being expressed in terms of equivalent quantities of NaOH, H_2SO_4 and HCl respectively.

TABLE V.

Estimations of the respective amounts of acid and alkali produced simultaneously in Solution (A).

	Kathode.		*Anode.*				
Experiment	Conditions	*Gain in alkalinity NaOH*	*Original equivalent alkalinity of electrolyte 50 c.c.*	*Amount of alkali added NaOH*	*Amount of H_2SO_4 required for titration*	*Equivalent gain in H_2SO_4*	*Equivalent gain in HCl*
1	1 cm., 23 S.W.G. electrode, 2 ma. currents, 10 minutes duration	**0·00052**	**0·2 c.c. $\frac{1}{100}$ NaOH**	**2 c.c. $\frac{1}{100}$ N**	**1·1 c.c. $\frac{1}{100}$ N**	**0·000539**	**0·00040095**
2		**0·00048**	**0·2 c.c. $\frac{1}{100}$ NaOH**	**2 c.c. $\frac{1}{100}$ N**	**0·9 c.c. $\frac{1}{100}$ N**	**0·000441**	**0·00032805**
3		**0·00072**	**0·2 c.c. $\frac{1}{100}$ NaOH**	**3 c.c. $\frac{1}{100}$ N**	**1·3 c.c. $\frac{1}{100}$ N**	**0·000637**	**0·00047385**
4		**0·00056**	**0·2 c.c. $\frac{1}{100}$ NaOH**	**4 c.c. $\frac{1}{100}$ N**	**0·8 c.c. $\frac{1}{100}$ N**	**0·000392**	**0·0002916**
5		**0·00052**	**0·2 c.c. $\frac{1}{100}$ NaOH**	**4 c.c. $\frac{1}{100}$ N**	**0·8 c.c. $\frac{1}{100}$ N**	**0·000392**	**0·0002916**
Total:		**0·0028**				**0·002401**	**0·00178605**

The addition of any substance to the solution subsequent to electrolysis must of necessity give rise to the possibility of error, and consequently I do not attach the same importance to these estimations as I do to the results obtained in previous experiments.

It is seen that the same uniformity in the amounts of alkali is not found as in previous experiments, a conspicuous difference being noticeable in experiment 3. If, however, these figures be compared with Table IV., experiment 2, wherein the same conditions obtained, it will be noticed that the results are almost identical, except in this one instance; the difference therefore is most probably due to experimental error.

With regard to the acid formation a comparatively wide variation is evident, but yet a marked relative proportionality exists between these quantities and those of the alkali simultaneously produced. For this reason, together with the fact that in different experiments different quantities of alkali were added without materially altering this proportion, I contend that the above figures may be regarded as a fairly accurate estimate of the actual residual quantities of acid which were produced.

It is further seen that the total amount of acid formed is very small having regard to the milliamperage of the current and duration of the electrolysis, the total amount formed being equivalent to 0·00178605 grm. HCl in five estimations, or an average per estimation of 0·00035721 grm. in ten minutes, produced by a current of 2 ma. Assuming the same analogy to exist in this as in the estimation of alkali, we ascertain that the amount produced under the influence of a current of 1 ma. acting for thirty seconds is 0·00000893025 grm. HCl (equivalent).

Now, since the equivalent of 0·0028 grm. NaOH is 0·0025506 grm. HCl it is apparent that equivalent amounts of acid and alkali have not been produced in these experiments, the total difference being equivalent to 0·00076455 grm. HCl in five estimations, and consequently an average difference of 0·00015291 grm. HCl in individual estimations, which represents, when reduced to terms of 1 ma. for thirty seconds, a difference only of 0·00000382275 grm. HCl.

This inequality in equivalent amounts of acid and alkali might have been anticipated from the fact that during electrolysis an appreciable quantity of chlorine was lost to the solution, and that a considerable quantity was invariably found throughout the experiments to remain free in the solution.

A similar phenomenon, namely, the escape of chlorine, has been already alluded to when proving the formation of acid in brain tissue under electrolysis; from analogy, therefore, a similar condition may be assumed to obtain in the neighbourhood of these lesions, a lesser quantity of acid being produced than alkali under identical conditions.

In comparing these results with those ascertained in experiments enumerated under Table I., in which the same electrolyte was examined, we find that the amount of acid produced is to the amount of alkali as 0·00000893025 grm. HCl is to 0·0000124 grm. NaOH, when currents of 1 ma. are utilized for electrolysis extending over a period of thirty seconds.

Since there is practically no difference in the quantities of alkali produced in the two electrolytes, and the object of this research has been to establish an analogy between the results herein ascertained and those which may be assumed to obtain in brain tissue under electrolysis, an average of eighty-seven experiments has been taken in which the estimation of alkali has been made, and the amount thus ascertained is found to be 0·0000133969 grm. NaOH.

It may be stated, therefore, that the amount of alkali produced is to the amount of acid as 0·0000133969 grm. NaOH is to 0·00000893025 grm. HCl, during electrolysis extending over a period of thirty seconds with 1 ma. current.

Certain definite conclusions are therefore arrived at from a consideration of these experiments: First, that in both solutions under the influence of electrolysis alkali and acid are produced at the kathode and anode respectively; secondly, that the amount in each is exceedingly small; and thirdly, that though there is a tendency to the slightly greater formation of alkali in the compound solution (B) than there is in (A), this difference is scarcely appreciable.

If it is allowed that there is an analogy between the results of these experiments and the changes which may be assumed to take place in brain matter under electrolysis, I contend that these figures afford strong presumptive evidence that in addition to chemical action other and more potent factors must be called into play in the production of these cerebral lesions. For although it cannot be doubted that they contribute somewhat to the result, yet having regard to their minute quantities and manner in which they are disseminated, it is difficult to conceive how they can have any definite bearing upon the production of these lesions.

For the above reasons I have carried this research a little farther, in order to ascertain to what extent the production of these lesions may be attributed not only to the volumes of gas evolved, but also to the nature of their evolution; for, from certain observations made during the preceding experiments, I was struck by the probability that such factors must have a very marked bearing not only on the production of the lesions, but also upon their nature and extent.

With regard to the evolution of the gases three facts were conspicuous: First, that the gases evolved had the power of carrying with them the product of dissociation, a point which has already been shown; secondly, that the gases produced at the kathode and anode differed very considerably in volume; and thirdly, that the density of the current had a distinct bearing not only upon the nature of their evolution, but also upon the actual volume produced.

The first point may be further demonstrated by adopting the same procedure as in previous experiments, having added to the anodal and kathodal chambers respectively one or two drops of dimethylamido-azo-benzol (0·5 per cent. alcoholic solution) and phenolphthalein (1 per cent. alcoholic solution). On closure of the current gas will be seen to be evolved at the two electrodes, and a faint rose pink tinge will be seen to be developed in the solution in the anodal chamber, more especially just under the meniscus, as evidence of the formation of an acid; this colour, however, rapidly disappears as the fluid becomes more saturated with chlorine.

In the kathodal chamber a very much more vivid and definite effect is produced; for simultaneously with the closure of the current a vivid flash of violet red is seen as evidence of alkali formation, which colour is first noticeable in the immediate vicinity of the electrode, and is then conveyed within the column of bubbles to the surface of the fluid, where, beneath the meniscus, it becomes rapidly accentuated and then gradually falls down the sides of the tube, producing the phenomena known as streaking.

These phenomena might be looked upon as the outcome of mechanical convection; but that this is not altogether the case may be shown by breaking the current suddenly, before the gases reach the surface; the streaking is then produced in the centre of the column of fluid, as though the gases were thereby deprived of their inherent power of conveying with them certain products of dissociation. This point is of practical importance when it is considered that through this inherent power the gases generated in brain tissue during electrolysis are capable of disseminating in the minutest manner possible the products of electrolytic dissociation, bringing them into immediate contact with every part with which these gases come in contact.

The second point is best illustrated by a survey of the following table, wherein is given a comparative estimation of the total volumes of gas which are liberated at the anode and kathode respectively, as also the volumes generated by currents of different density.

For the purpose of these estimates, the apparatus was inverted and the gases were collected in small graduated glass cylinders inverted over the electrodes and immersed within the solution within the respective limbs of the apparatus, electrodes of the same and different calibre being used for the purposes of comparative estimations.

TABLE VI.

Simultaneous estimations of the total volumes of gas liberated at the anode and kathode respectively by means of a current of 2 *ma., the electrodes being platinum* 1 *cm. long,* 23 *Imp. S.W.G., and* $\frac{1}{2}$ mm., $\frac{1}{10}$ *mm. in diameter; barometer* 30·5; *thermometer* 14° *C. Solution (A).*

Kathode.			*Anode.*		
Large electrode 1 cm., 23 Imp. S.W.G.	*Volume of gas in c.c.*	Small electrode $\frac{1}{2}$ mm. $\frac{1}{10}$ mm.	Large electrode 1 cm., 23 Imp. S.W.G.	*Volume of gas in c c.*	Small electrode $\frac{1}{2}$ mm , $\frac{1}{10}$ mm.
Time in minutes		Time in minutes	Time in minutes		Time in minutes
5	**0·05**	4	20	**0·05**	24
7·5	**0·1**	7·5	36	**0 1**	47
11	**0·15**	10·5	50	**0·15**	66
15	**0·2**	14	60	**0·2**	86
18·5	**0·25**	17	80	**0·25**	104
20·5	**0·3**	20	95	**0·3**	122
24·5	**0·35**	25	108	**0 35**	145
29	**0·4**	27	120	**0·4**	168
31	**0·45**	30·5	133	**0 45**	187
34·5	**0·5**	34·5	147	**0·5**	208
Average	**0·05 c.c.**	**in 3·45 minutes**	**Average 0·05 c.c. in 14·7 minutes**		**Average 0·05 c.c. in 20 8 minutes**

Owing to the length of time required to obtain appreciable quantities of gas a current of 2 ma. was used; and for the same reason extremes in the calibre of the electrodes were adopted in order to ascertain the effect produced in the volumes of the gas by currents of different density.

Three points are here clearly indicated:—

First, that an appreciable volume of gas is generated in all instances.

Secondly, that the volume generated at the kathode in each instance is far larger than that generated at the anode; and

Thirdly, that the volume generated at the kathode is unaffected by the density of the current, whereas at the anode a marked contrast exists in this respect.

It is seen that whether generated at the larger or smaller electrode the volume of gas at the kathode is the same, 0·5 c.c. being generated in 34·5 minutes under a current of 2 ma., or 0·05 in 3·45 minutes. The second point is a matter of practical importance when applied to the subject under review, a fact which is well illustrated by an examination of the cerebral lesions produced by electrolysis, wherein it is seen that the kathodal lesion is large and diffuse when compared with the anodal lesion, which is small and defined (*vide* photos Horsley and Clarke [1]).

The third point is also of very practical interest as illustrating a means whereby the volumes of gas eliminated may be controlled.

Throughout the experiments enumerated in the above and following tables it was observed that the rate of evolution of these gases was in individual cases constant, and that a definite proportional relation existed between the volume of gas and duration of electrolysis. This is a point of further interest and importance, since in accordance with Faraday's laws of electro-chemical equivalents and definite proportions it affords conclusive evidence of the accuracy of the estimations enumerated in Tables II., III. and IV., wherein it was shown that the quantities of alkali produced were in no way dependent upon the calibre of the electrode, provided the quantity of electricity was constant, and further that the quantities of alkali were proportional to the duration and milliamperage of the current. The proportion here established likewise proves in accordance with these laws that the same relation exists between the milliamperage of the current and volume of gas generated under identical conditions. Consequently the amount of gas which was estimated in the above experiments is in every instance double that which would obtain under the influence of 1 ma. current. The following results therefore are ascertained: that the actual volume of gas which is generated within the electrolyte (A) in thirty seconds with 1 ma. current is respectively 0·00362 c.c. at the kathode under any circumstances, and 0·0008 c.c. at the larger anode, as against 0·0006 c.c. at the smaller anode.

Since the results herein ascertained are in accordance with the quantitative estimates of the alkalies produced, and also in conformity with certain definite conditions observed in the lesions by Horsley and Clarke [1], it may be assumed that the above figures are a fairly approximate estimate of the volumes of gas which are generated in brain tissue; for such estimations bear a distinct relationship to the nature and extent of the lesions produced under analogous conditions.

Although it is practically impossible to estimate the complexity of reactions which are actually responsible for the variation in the volumes of gas generated at the respective anodes, it is certain that such must, in this instance, be the direct outcome of the density of the currents, whereby subsidiary actions are produced, for in all other respects the conditions were identical.

This illustrates a point of the utmost practical importance when considering the production of these cerebral lesions; for it is seen that for any given current the greater its density the smaller is the volume of gas liberated at the anodal electrode; and thereby is illustrated a means of confining within certain limits the nature and extent of the lesion.

In order to verify these results three further experiments were undertaken, from which it will be seen that the conclusions arrived at were almost identical with those enumerated in Table VI.

TABLE VII.

Simultaneous estimations with regard to the total volumes of gas generated at the anode and kathode respectively. Large electrode 23 Imp. S.W.G.; small electrode ½ mm. long and $\frac{1}{10}$ mm. in diameter.

Kathode.			*Anode.*		
Large electrode 1 cm., 23 Imp. S.W.G.	*Volume of gas in c.c.*	Small electrode ½ mm., $\frac{1}{10}$ mm.	Large electrode 1 cm, 23 Imp. S.W.G.	*Volume of gas in c.c.*	Small electrode ½ mm., $\frac{1}{10}$ mm.
Time in minutes		Time in minutes	Time in minutes		Time in minutes
	0·5	35		0·05	24
				0·1	48
				0·15	66
				0·2	83
				0·25	102
35	0·5		18	0·05	
			30	0·1	
			43	0·15	
			56	0·2	
			70	0·25	
	0·5	35		0·05	23
				0·1	45
				0·15	65
				0·2	82
				0·25	98

Owing to the time required to produce appreciable quantities of gas at the anode, estimations in the above were only conducted for a period when 0·25 c.c. of gas had been generated. The thermometer in these experiments was 16° C.; the barometric pressure I failed to note; such, however, can have but little bearing on the point under review, since the volume of gases is so small that any difference would be inappreciable.

From the last two series of experiments as to the volumes of gases liberated at the respective electrodes under different conditions, the following definite conclusions may be stated:—

First, that the total volumes of gas vary considerably at the kathode and anode respectively, but in all instances are appreciable in quantity.

Secondly, that the volume of gas generated at the kathode in a given time is unaffected by the density of the current.

Thirdly, that in every instance the volume of the gas generated by a given current in a given time at the kathode is greater than the volume of gas simultaneously liberated at the anode, and

Lastly, that the volume of gas generated at the anode varies directly with the size of the electrode, and indirectly as density of the current.

The last conclusion may be briefly stated as follows :—

That provided the milliamperage of the current is constant, the smaller the anodal electrode the smaller will be the volume of gas which is generated. This is a point of much practical interest in the electrolysis of cerebral substance, and is amply borne out by the minute accurately defined lesions which are obtained when these conditions have been adopted.

From the above facts as to the actual volumes of the gases which are produced it must be granted that, apart from any chemical action which they may possess, their mere volume must have a definite mechanical effect in cerebral tissue, and this is illustrated by the character of these lesions (Horsley and Clarke [1]). But I contend that a more potent factor has still to be established in order to account for certain mechanical effects which are apparent in these lesions, wherein the actual volume of gas produced must be exceedingly minute.

The point to which I now allude is the marked mechanical effect which is produced, not so much by the actual volume of the gases as by the manner of their generation. This factor is undoubtedly dependent on the density of the current, owing to the initial impetus with which the gases are ejected from the electrode.

During all the previous experiments it was observed that although the gases might be developed in equal volume in a given time with a given current, yet the precise nature of this evolution differed essentially with the size of the electrode. This was most definite in the estimation of the volumes of gases liberated at the kathodes under currents of identical milliamperage, wherein comparatively large but equal volumes of gas were generated, though the electrodes varied widely in calibre.

This phenomenon was further well illustrated by using the apparatus above alluded to, and filling it with solution (A), to which three or four drops of phenolphthalein (1 per cent. alcoholic solution) had been added; the electrodes used were of different calibre, 1 cm. 23 Imp. S.W.G., and $\frac{1}{2}$ mm. by $\frac{1}{10}$ mm., and the instrument was inverted, the current used being 2 ma., regulated and measured by a rheostat and galvanometer. The large electrode now being the kathode, the current was closed, when simultaneously a violet red atmosphere was seen to surround the electrode, the electrode itself momentarily assuming the appearance of a piece of muffed glass, a condition which was due to minute gaseous particles which were seen adhering to it. As the current continued, these, however, rapidly ran together and, assuming considerable size, were slowly discharged from the electrode and passed to the surface of the fluid. The apparatus was now shaken to disseminate any colour and gas from either electrode and the current reversed. The smaller electrode being now the kathode, the current was closed, and a very much more striking effect was produced, for simultaneously with the closure of the current a vivid flash of rose red appeared, and was rushed through the centre of the column of fluid by means of the jets of gas which were discharged from the electrode, which in itself was covered by a seething mass of minute bubbles, which were ejected from the electrode with marked initial velocity.

It was noticed that the indicator of the galvanometer was not absolutely stationary, a slight but regular ticking being seen as evidence of the polarizing and depolarization of the electrode due to the evolution and discharge of its gas, an effect which is well illustrated in the following photograph (fig. 2).

That mechanical energy is here displayed is undoubted, and to this factor I attribute many of the phenomena which are evidenced in the cerebral lesions produced by electrolysis. For such mechanical energy cannot but produce marked distension in a substance such as cerebral tissue: the effect produced being in direct ratio to the density of the current and volumes of gas liberated.

To this fact I have already alluded, and it is therefore only necessary for me to observe that the strongest evidence of this mechanical energy is invariably displayed in all the cerebral lesions which I have seen produced by electro-chemical means (*see* Horsley and Clarke, figs. 20 *et seq.*, p. 98 of this volume.

Such lesions as above alluded to were in every instance produced by currents of comparatively high density analogous to those above enumerated, for minute electrodes were invariably used, with currents such as were examined in the above experiments and generated by a battery of like voltage. The gases which produced these lesions were therefore generated with marked potential energy, thus giving rise to a distension of the tissues and laceration of the vessels in the neighbourhood of the electrode, thus producing hæmorrhage not only in the immediate neighbourhood of the electrode, but also radiating into those perivascular spaces into which the gases had forced their way.

A similar, but less marked, mechanical energy was displayed on examining the anodal electrodes under identical conditions; and an examination of the sections of these lesions, together with the photographs, proves that this phenomenon bears a definite relation to the conditions therein observed, for though the gases are still generated at a high density, their actual volumes are less, and consequently less destructive lesions were produced, a fact which is clearly evidenced by their compact and defined outline.

A consideration of this mechanical energy impresses one with the importance and bearing which this factor must have, not only in the production of the lesions in brain tissue, but also upon their nature and extent. In order further to illustrate this point from a practical standpoint a simple experiment was performed; instead of a single kathodal electrode, two electrodes of "apparently" similar calibre were made responsible for the kathodal dissociation, and we thereby obtained some idea of the great difference which may actually take place during electrolysis when precisely identical conditions are not observed. A fine thin platinum wire $\frac{1}{10}$ mm. in diameter was doubled upon itself, one end being insulated within a fine glass capillary tube, which was sealed $\frac{1}{2}$ mm. from the tip of the wire; the other end was similarly insulated within a closely insulating glass cylinder of the same dimensions, which permitted $\frac{1}{2}$ mm. of the wire to project; this cylinder, however, was not sealed upon the wire, which was retained in place by a small piece of wax, which did not close the actual lumen of the tube. The loop in the centre of this wire was now connected with the negative side of a battery, and the two kathodal electrodes inserted in the bottom of a narrow glass cell, containing solution (A), to which a drop of phenolphthalein solution was added. The anode was now inserted in the top of the cell equidistant from each kathode, and a current of 1 ma. utilized for electrolysis. The effect produced on closure of the current is exceedingly well represented in the accompanying photograph (fig. 2), which was taken by Sir Victor Horsley one-fifth of a second after closure of the current.

Striking evidence of the conditions which were actually observed is shown by the photograph, for simultaneously with the closure of the current a vivid flash of colour and immediate rush of gas took place from B, whereas for an appreciable interval nothing was observed at A, after which a large bubble appeared at the mouth of the glass insulating tube, and a few minute bubbles were evolved from the point of the wire;

these passed slowly through the solution, carrying with them a faint violet red colour, a certain amount of which was also noticeable within the glass insulating cylinder, from which a drop of coloured fluid subsequently escaped.

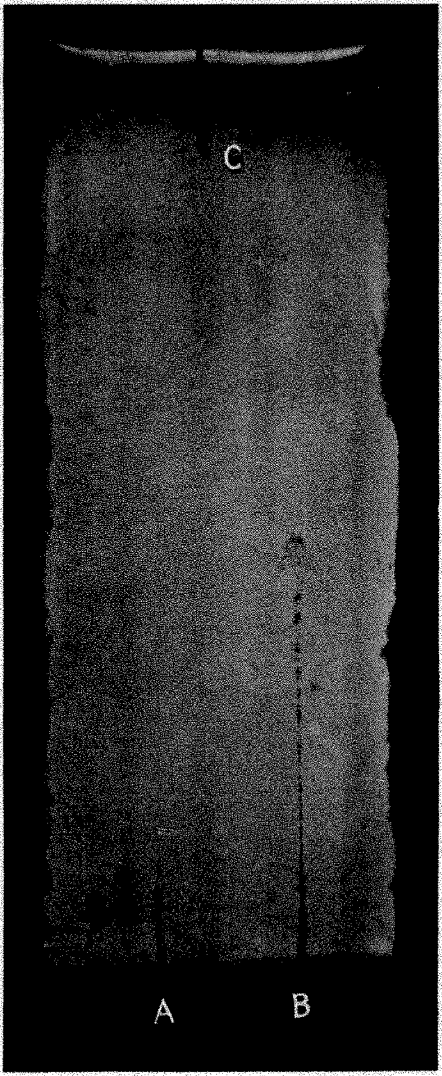

FIG. 2.

Glass cell and electrodes magnified two diameters: A, ineffectually insulated kathodal electrode; B, effectually insulated kathodal electrode; C, single anodal electrode. Current 1 ma. $\frac{1}{5}$ second after closure of current; $\frac{1}{2}$ mm. of wire projecting from each glass cylinder of the kathodal electrodes.

This experiment undoubtedly proves that a much more vivid electro-chemical reaction took place at B than at A, although it is probable that the quantity of electricity which passed through it was less than that which passed through A, owing to the greater resistance offered by the smaller area exposed to the electrolyte.

These phenomena clearly indicate that the electrolyte sustained considerable loss both in mechanical effect and chemical reaction, through wasted energy within the cylinder of the ineffectually insulated electrode.

From the "apparent" similarity in area of the actual electrodes exposed to the electrolyte within the cell, it might have been assumed that the ultimate results must be the same; but the above facts clearly prove the fallacy of any such supposition and show how great a difference may actually exist in instances where the conditions are not absolutely identical.

The experiment is of the utmost practical importance in proving the absolute necessity for accurate and effective insulation of the electrodes when uniform results, such as are essential in cerebral investigation, are most desirable.

The only means by which this can be attained is by accurate and effective sealing of the insulator at its distal extremity. When this is effected it is certain that the whole of the current which is actually registered must produce its products of dissociation within the brain substance, and not within the capillary container of the electrode, or even entirely without the brain substance through partial or complete short circuiting of the current; this is not only possible but very probable wherever it is essential to keep the tissues continually moistened during such investigation. What is here laid down with regard to electrolysis applies equally to faradic stimulation.

A practical difficulty is encountered in securing insulation of this nature when delicate glass cylinders are utilized for the purpose; for if they have been sealed upon the electrode, expansion during electrolysis and other factors are liable to crack the glass at the point of insulation; this difficulty is, however, readily overcome by utilizing a speck of rubber solution, or some such substance, in order to seal the distal extremity of the tube, for, unless this be done, capillary attraction draws within it the fluids of the part, and loss and uncertainty in the effects of electro-chemical reaction are inevitable.

That other factors than those above enumerated must inevitably contribute towards the formation of these cerebral lesions is only too apparent, having regard to the complexity of reactions which must of necessity result from the electrolytic dissociation of a substance so complex as blood.

Yet, having regard to certain of the products of electrolysis as proved in the above experiments, many of the actual chemical changes which take place in blood-serum under analogous conditions may be ascertained by a reference to Starling's "Elements of Human Physiology" [2], from which an insight may be gained regarding many of the actual chemical reactions which are therein produced. Into so large a subject as this I regret I have not the ability to enter, and will now therefore but state certain conclusions which may be gathered from a consideration of the foregoing experiments.

Before doing so it is essential to state that for the purpose of these experiments only I have assumed that the acid formed as the outcome of electrolysis of these solutions was due to hydrochloric acid. Such presumption is inaccurate and justified only by the necessity for selecting some acid in respect of which comparative estimations might be made.

It is possible, as already pointed out, that a minute trace of hydrochloric acid is formed, but the major part of the acidity found in the solution at the anode after electrolysis of the solution (A) is not due to hydrochloric acid as such; for the chlorine herein liberated does not actually attack the water, but simply aids in its dissociation, remaining itself in simple solution as hydrolysed ions; the water is dissociated as hydrion and hydroxidion, the oxygen being then liberated from the hydroxidion, leaving a preponderating quantity of hydrion in solution; to this the whole or major portion of the acidity is probably accountable. That a like condition is also the outcome of electrolytic dissociation of solution (B) is evident from a consideration of its constituents.

With regard to other products of anodal dissociation, however, it has been shown that a very small, but yet appreciable volume of gas is produced; yet the point which is of the most practical importance is that free chlorine is undoubtedly liberated, and owing to its potency it must have a certain influence in the production of these lesions.

In kathodal dissociation, however, no doubt exists as to the formation of an alkali, which in solution (A) is sodium hydroxyl; this is the case also in solution (B), though other alkalies, notably potassium hydroxyl, are also produced, an equivalent quantity of hydrogen being liberated, which gas has been proved to have the power of conveying with it during electrolysis these alkalies, which must also have a definite bearing upon the production of these lesions. The same alkalies are also formed in solution (B) and blood-serum as the outcome of its electrolytic dissociation owing to their similarity in inorganic content.

From the above experiments the following conclusions may be summarized:—

(1) That the definite alkalies sodium hydroxyl and potassium hydroxyl—and possibly a minute trace of other alkalies—are formed in brain tissue under the influence of electrolysis, the total amount produced with a current of 1 ma. in thirty seconds being equivalent to 0·000013396 grm. NaOH.

(2) That an acid is produced at a positive electrode which may be due to numerous causes; the chief of these are most probably hydrion, hydrochlorite, and hydrochloric acid, the total quantity of which when eliminated at an electrode of 1 cm. long, 23 Imp. S.W.G., is equivalent to 0·00000893 grm. HCl, or 0·000012005 grm. H_2SO_4 with the current of 1 ma. in thirty seconds.

(3) That hydrogen is liberated at the kathode which preponderates in volume over the gases generated at the anode, in the proportion of 4 to 1 or 6 to 1, in accordance with the density of the anodal current.

(4) That the total volume of hydrogen generated is 0·00362 c.c. with the current of 1 ma. in thirty seconds no matter what be the density of the current.

(5) That the hydrogen gas has the power of conveying with it into the tissue other products of dissociation, *e.g.*, NaOH, and KOH.

(6) That the volume of hydrogen is constant, no matter what be the calibre of the electrode, provided the quantity of electricity is the same.

(7) That oxygen gas which is generated at the anode has the power of conveying with it into the tissues other products of dissociation, *e.g.*, chlorine.

(8) That the total volume of the gases liberated at the anode varies indirectly with the density of the current.

(9) That the total volume of gases generated at an anode 1 cm. long 23 Imp. S.W.G. is 0·0008 c.c., as against 0·0006 c.c. at an electrode $\frac{1}{2}$ mm., $\frac{1}{10}$ mm., with a current of 1 ma. in thirty seconds.

(10) That the density of the current in all instances has a marked bearing upon the mechanical energy of the gases generated during electrolysis, and consequently it is probable that it must have a similar bearing not only in the production of the cerebral lesions, but also in their nature and extent under analogous conditions.

(11) That provided the milliamperage of the current is constant, the mechanical effect produced is in inverse ratio to the size of the electrode; this effect, however, is somewhat modified at the anodal electrode, since the greater the density the smaller are the volumes of the gases liberated.

(12) That with a given current producing electrolysis, the smallest volume of gas is generated at the smallest anodal electrode in any given time.

From a review of the above facts as to the products of electrolytic dissociation, taken together with certain definite conditions ascertained and set forth by Horsley and Clarke [1], with which these results run parallel, it is most probable that, though chemical reaction bears a definite part in the production of these lesions, yet the mechanical element (due to the evolution of the gases) is the main factor in their production; more especially is this the case in the kathodal lesions, wherein comparatively large volumes of gas are generated, and to a lesser extent in the anodal lesions, wherein smaller volumes of gas are liberated, although such are here of a more potent nature.

The accuracy of this statement was tested by Horsley and Clarke, who injected the brain with similar quantities of alkalies as above estimated, without producing results in any way comparable with those obtained by electrolysis; the disintegrating effects of which, through the rush of ions to and from the electrodes, must aid materially in the production of these lesions.

As the outcome of facts elicited in the above experiments, it may be stated that with a current of certain known milliamperage, and an electrode of constant composition and accurate dimensions, provided short circuiting outside the actual brain substance be prevented, a means is afforded whereby in any instance it is possible to produce within that tissue lesions of uniform and definite dimensions: for the resistance in brain tissue may readily be ascertained prior to electrolysis although for all practical purposes it may be regarded as virtually constant. This accuracy, however, I maintain, can only be ensured when the electrode is "effectually insulated" at its distal extremity as above illustrated (fig. 2); otherwise loss of electro-chemical effect must result and irregular polarization and consequent variation in the density of the current are inevitable, whereby minute accuracy and uniformity in results are rendered impossible.

In conclusion I trust that the above observations may be of interest to those who are investigating the minute topographical anatomy of the central nervous system by electro-chemical means.

I have to thank Sir Victor Horsley and Dr. R. H. Clarke for having permitted me to be present during many of their investigations, and also Professor Vaughan Harley for the use of his laboratory in University College, where this research was carried out; and likewise Dr. Francis W. Goodbody for his kind assistance.

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FAMILIAL ATROPHY OF THE HAND MUSCLES.

BY THEODORE THOMPSON, M.D., M.R.C.P.,

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WASTING of the muscles of the hands is a symptom common to many forms of nervous disease, but cases are rarely found occurring together in family groups. In the muscular dystrophies, where several members of a family are, as a rule, affected, wasting of the hand muscles is extremely uncommon. Again, in cases where the wasting of the hand muscles is due to disease of the spinal cord or peripheral nerves, it is very unusual to find the cases occurring in families.

An account of the Lewis family would therefore seem worthy of record. Out of sixty-four individuals forming five generations seven persons were affected with atrophy of the muscles of the hand.

Case 1.—Helen Lewis (No. 49 in the Table) came under my care at the Poplar Hospital for an attack of cardiac pain. She was a well-developed girl of 20 years of age. At 4 years old she was taken to a hospital for an attack of purpura; she had had occasional aching pains in the legs, but there was no definite history of acute rheumatism; she had never had scarlet fever, but had suffered from measles when a baby.

On examination, both the left and the right sides of the heart were somewhat enlarged. There was a systolic murmur at the mitral area, and a diastolic aortic murmur could also be heard; the pulse was somewhat collapsing in character; she had slight cough and the bases of the lungs showed evidence of engorgement; there was slight œdema of the feet, but the liver was not enlarged.

Under treatment the cardiac condition improved and she was discharged in three weeks time with good compensation.

While in the hospital the curious condition of both hands was noticed. The muscles of both hands were extremely wasted and formed a striking contrast to the well-developed muscles of her arms and forearms.

The patient herself noticed that her hands began to get thinner when she was about 16. She had no trouble with them until she went into domestic service at 17, when she noticed that she could not do needlework easily, nor could she pick up small objects without difficulty. She was, however, able to do her ordinary work of scrubbing and cleaning well. Within the last year or two she had noticed that the hands were getting worse and that the fingers were becoming so bent that she could not straighten them.

In the right hand there was distinct wasting of both the thenar and the hypothenar eminences. The thumb was drawn back by the extensor thumb muscles to a level with the palm, and the flexor tendons showed up prominently upon the palmar surface of the hand. The fingers were hyperextended at the metacarpo-phalangeal joints and were flexed at the interphalangeal joints. As

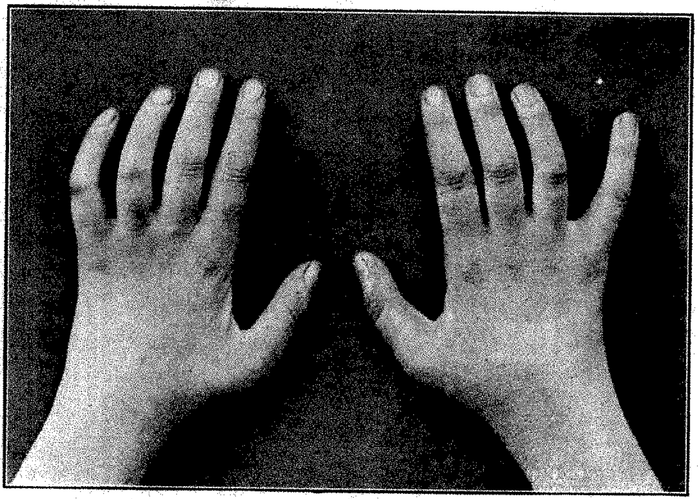


FIG. 1.

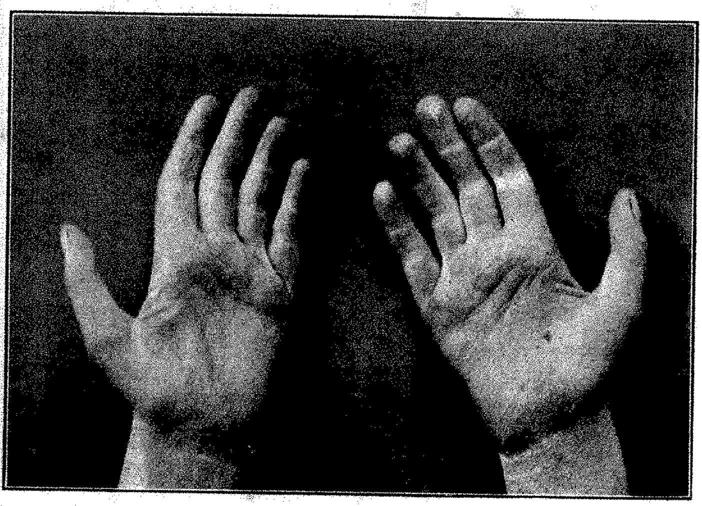


FIG. 2.

regards the movements of the fingers, the thumb could be opposed to each of the four fingers in turn, but the movement was carried out slowly and with difficulty. The thumb could also be slightly abducted from the palm, but could not be moved in a direction perpendicular to the plane of the palm. The left hand was in a condition exactly similar to the right. The changes in the hands are well shown in the accompanying photographs (figs. 1 and 2), in which the extreme wasting of the interossei as well of the muscles of the thenar and hypothenar eminences can be well seen.

The muscles of the forearms and arms were strong and well developed, as were also the muscles round the shoulder-joints. There was no winging of the scapulæ. The face was natural in appearance and all the facial muscles acted well; the movements of the eyeball were normal, and the pupils reacted both to light and to accommodation. The tongue and the palate moved normally. The two sides of the chest expanded equally and there was no scoliosis of the spine. The muscles of the abdomen were normal, the leg muscles were strong and well developed, and there was no alteration whatever in the shape of the feet, nor was there any difficulty in walking.

Electrical reactions.—The muscular reactions in the left hand were very distinctly altered. None of the small muscles of the hand gave any response to the faradic current, and the majority of the muscles did not react to strong galvanic currents. The small adductor muscles of the thumb and of the little finger gave a slight response to a strong galvanic current, but the excitability of these muscles was evidently greatly diminished. A slight reaction was also obtained in the second interosseous muscle with the galvanic current. In the right hand this condition was even more marked, and no reaction could be obtained with either the faradic or the galvanic current in any of the muscles with the exception of the adductors of the thumb, which reacted slightly to the galvanic current.

Reflexes.—The knee-jerks were normal and the plantar reflex was of the flexor type; the triceps-jerk could be obtained easily on both sides, but the supinator-jerk was not obtained on either side.

Sensation.—During the whole time that the patient has noticed the condition of her hands there has never been any pain; she noticed, however, that they seemed to be worse in the cold weather. Sensation to touch, to heat, to cold, and to the pain of a pin-prick were perfectly normal in both hands, forearms and arms. The compass-points could be distinguished from one another over the hands and forearms within the normal limits. Thus over both palms the answers given were correct when the points were separated for a distance of 1·5 cm., while over the forearm the two points could be clearly distinguished from one point when separated for a distance of 3·5 cm.

A radiograph (fig. 3) of the upper part of the spinal column showed much enlargement of the transverse processes of the seventh cervical vertebra. On palpation, no tumour corresponding to these enlarged transverse processes could be made out at the root of the neck.

After her discharge from the Poplar Hospital her hands were treated by the sinusoidal current bath for several weeks, and she thought that some improvement had taken place and that the fingers were not so much bent as they were before.

While in the hospital she stated that there were several cases of this wasting of the hands in her family, and that, as the family was a large one, its members were continually on the look-out to see if any of them would be affected with hand wasting. She said her father suffered in the same way as herself.

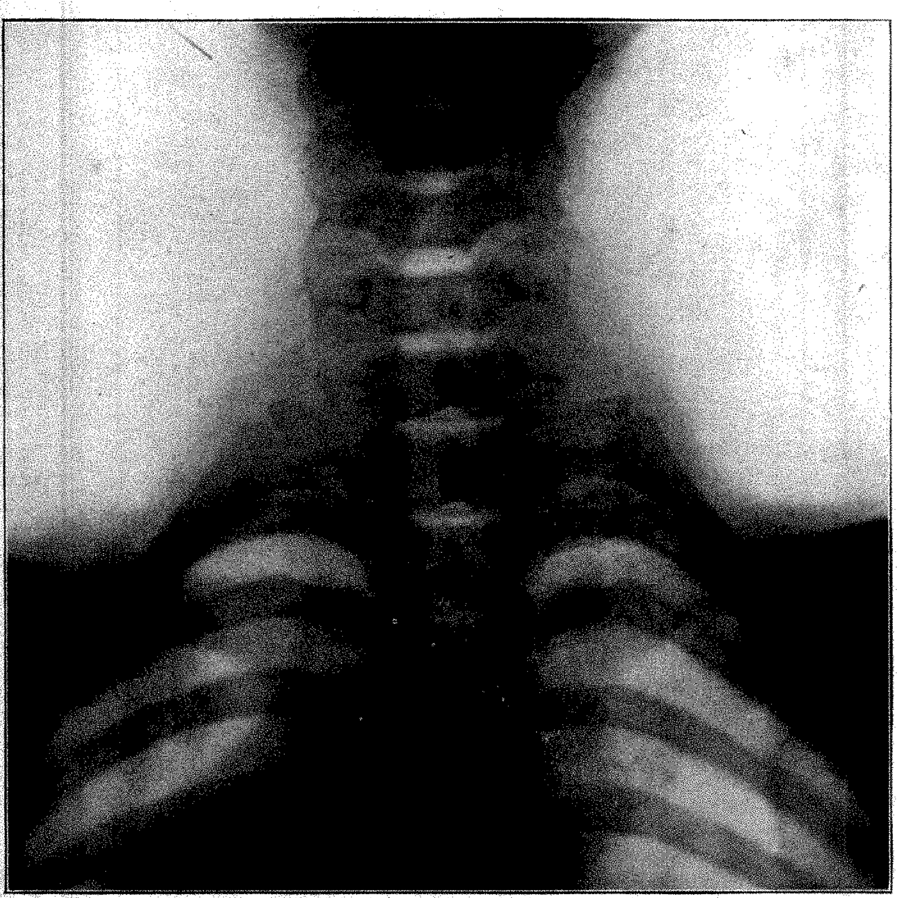


FIG. 3.

Case 2.—Frederick Lewis (No. 17 in the Table), and father of Helen Lewis, kindly came up to the hospital and allowed his hands to be examined.

He was a powerfully built dock labourer. When 16 to 17 years old, he began to notice that the right thumb was becoming thin; the left hand became affected soon after. This wasting gradually got worse until most of the muscles of the hands were affected, but the condition had not changed much of late years. There had never been any pain whatever, but his hands were apt to get numb when the weather was cold. He was able to do his work as a dock labourer well, and, with the help of his mate, could lift 2 cwt. of oil-cake, and he could lift ½ cwt. by himself. He found, however, that he could not use his hands to pick up anything very small, especially when they were cold.

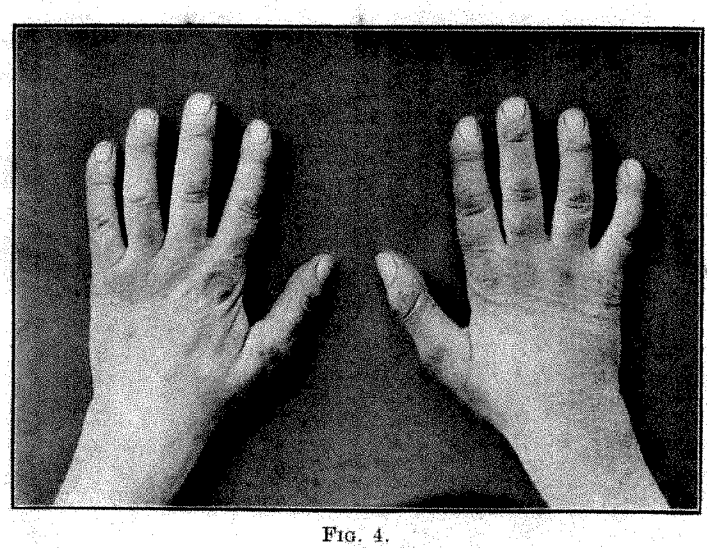


FIG. 4.

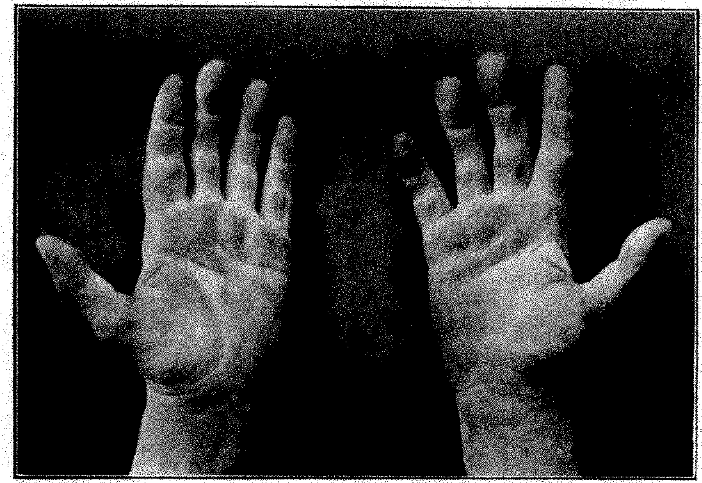


FIG. 5.

In his right hand the thenar eminence was much wasted, and the hypothenar to a less extent. The first interosseous muscle was profoundly wasted, and to a less extent the other interosseous muscles. The thumb was extended and lay in the plane of the palm; the movements of opposition of the fingers and thumb were feeble, but could be performed in each case; abduction and adduction of the thumb were very feeble and the interosseous movements were absent. The wasting of the hands is well shown in figs. 4 and 5.

Electrical reactions.—All the intrinsic muscles of the hand reacted feebly to galvanism and not at all to faradism. There is no response until the galvanic current is raised as high as 10 ma. to 20 ma. No response at all could be obtained from the abductor and the opponens muscles of the thumb, while the abductor minimi digitii reacted better than the other small muscles of the hand.

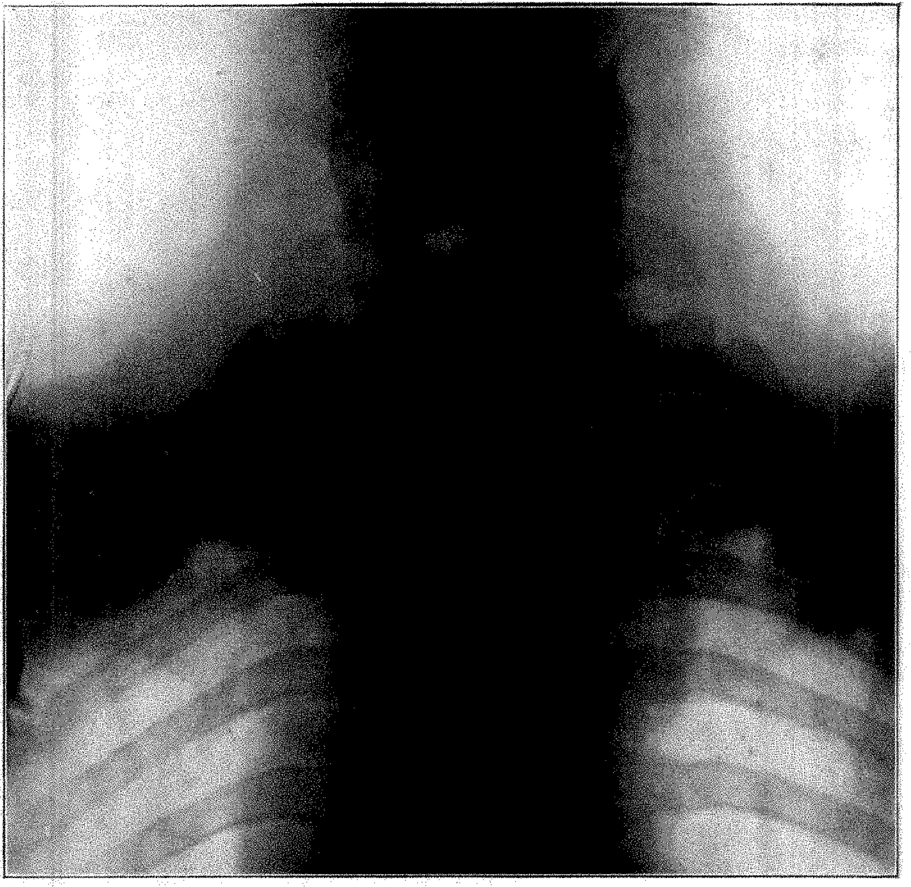


FIG. 6.

The left hand is in a condition similar to that of the right, but the wasting is, if anything, more extensive, and on the left side the patient was unable to approximate the tip of the little finger to the end of the thumb.

The muscles of the arms, forearms and legs were perfectly normal, and there was no alteration in the shape of the feet and no difficulty in walking.

Reflexes.—The knee-jerks were normal, the triceps-jerks were easily obtained, but the supinator-jerks could not be obtained on either side.

Sensation.—There had never been any pain at any time, but he found that his hands got numb in the cold weather. No sensory changes could be found on examination.

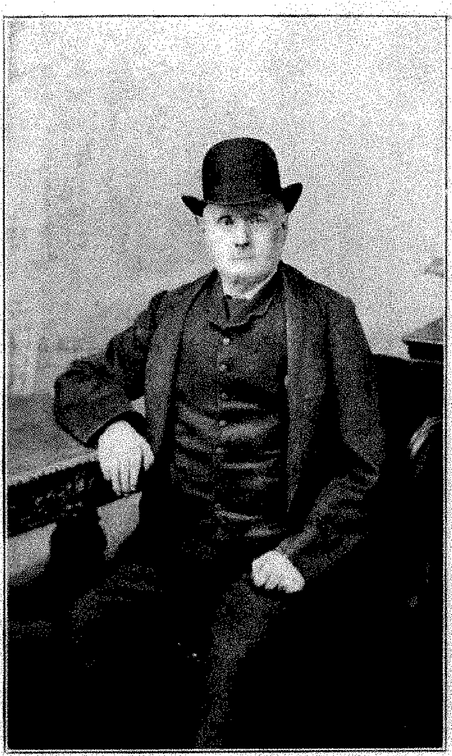


FIG. 7.

A radiograph (fig. 6) of the upper part of the spinal column showed the presence of seventh cervical ribs, which appeared to be equally developed on the two sides. On palpation of the root of the neck it was impossible to feel any swelling corresponding to these cervical ribs.

Case 3.—Thomas S. (No. 6 in the Table) is now dead, but as he was well known to his nephew, whose case has just been recorded, it seemed best to refer to him in this place. He was known to have had wasting of the muscles of both hands, which came on when he was a young man, and which, though causing him some slight disability, never interfered with his work as a dock labourer. He lived till the age of 82, and no muscles were ever affected except the muscles of his hands. By a fortunate chance I have been able to obtain a full length photograph of him two years before he died (fig. 7). This portrait shows distinct wasting of both hands.

The other members of this family have been collected in the accompanying table. I have only been able to examine the two cases already described where the wasting of the hand muscles existed. The other four affected cases could either not be traced or lived out of England.

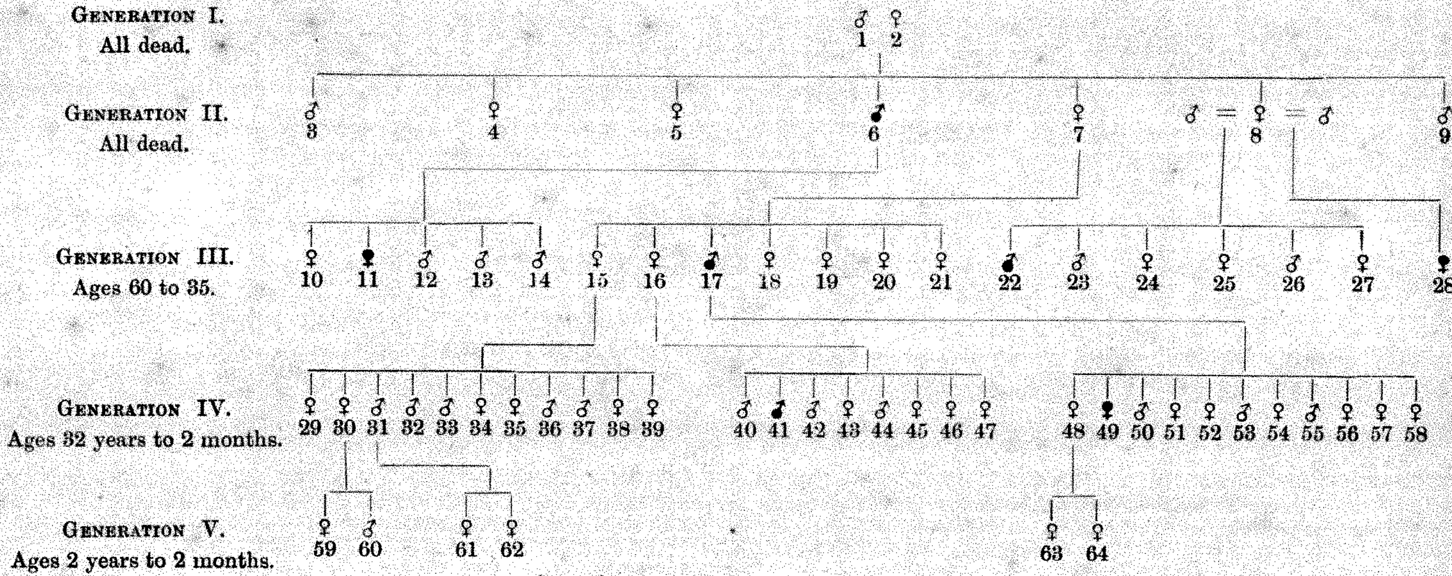
I have, however, been able to examine personally a very large number of the remaining fifty-seven cases, while for those who were either dead or inaccessible I have in every case been able to obtain first-hand evidence as to the condition of the hands.

Full details will be found in the explanation attached to the genealogical tree.

The condition here described as occurring in the Lewis family might be due to some defect in the muscular supply of the hand, or it might be caused by some other primary condition. It seems to me probable that the wasting of the hands is secondary, and that it is caused by the presence of the seventh cervical ribs, which are well known to occur in families. The two radiographs (figs. 8 and 9) are taken from two patients (father and son) under Mr. Sherren, who has kindly allowed me to reproduce them. The boy was brought by the father for some other complaint, and it was noticed that the child had prominent seventh cervical ribs. The ribs could also be felt in the case of the father. In neither case had the ribs produced any symptoms. These cases illustrate the familial characters of cervical ribs, and also the fact that the large and horizontally placed cervical ribs often produce no symptoms.

Against the hypothesis that the wasting of the hands is due to the presence of seventh cervical ribs the following objections may be urged:—

(1) That the condition is symmetrical. It has been pointed out by all observers on the conditions produced by cervical ribs that the symptoms produced are generally unilateral. On the other hand, the abnormality is practically always bilateral, being usually more marked on the one side than the other. Of the sixteen cases described by Hinds Howell [4], in all the deformity was bilateral, but in all cases, with one exception, the symptoms were unilateral. There seems, however, no reason at all why in certain cases the cervical ribs could not be equally developed and produce symptoms on both sides. In fact the cases originally described by Lewis Jones [6] in 1893 were considered under the title of "Symmetrical Atrophy affecting the Hands in Young People." It is interesting



Sixty-four individuals in five generations. Seven persons affected.

1. Long since dead. Three of the grandchildren (Nos. 15, 16 and 17) all declare that the hands were not affected.
2. Same evidence as No. 1 as to non-affection of the hands.
3. Died a single man. Said by Nos. 15, 16 and 17 to be unaffected.

4 and 5. Stated by Nos. 15, 16 and 17 to be unaffected. Lost sight of for many years.

6. Case 3. Description with photograph in the text.
7. Mother of Case 2 (No. 17). Nos. 15, 16 and 17 and the wife of No. 17 knew her to be unaffected.
8. Aunt of Case 2 (No. 17). Well known to be unaffected by No. 17 and his wife.
9. Known by No. 17 to be unaffected.
11. Seen by No. 17 for many years and known by him to have wasting of the hands.

10, 12, 13 and 14. All known to be unaffected by No. 17, but, like No. 11, have been lost sight of for years.

15. Personally examined. Unaffected. No cervical rib felt.
16. Personally examined. Hands unaffected. No cervical rib felt.
17. Case 2. Full details in the text.
18. Dead, of phthisis. Known by Nos. 15, 16 and 17 to be unaffected.

19, 20 and 21. Are all in Canada. Known by Nos. 15, 16 and 17 to be unaffected.

22 and 28. Both seen by No. 17 and his wife, and the wasting of the hands seen.

23, 24, 25, 26 and 27. All known to be unaffected by No. 17 and his wife. Lost sight of for years.

29. Personally examined. Hands unaffected. No cervical rib felt. Aged 32.

30, 31, 32, 33, 34, 35, 36, 37 and 38. Said by their mother (No. 15) to be unaffected. Ages 30 years to 5 years.

39. Personally examined. Hands unaffected. No cervical rib felt.
40. Stated by his mother (No. 16) and his cousin (No. 49) to be unaffected. Aged 23.
41. Now in Canada. Aged 21. His hands began to waste soon after he started work at 14 years old. He can still do heavy work, but cannot pick up small things. Well known to Nos. 16, 17 and his cousin (No. 49).

42, 43, 44, 45, 46 and 47. Ages 20 years to 7 years. All personally examined, and the hands found to be unaffected and no cervical ribs to be felt.

48. Aged 22. Personally examined. Hands and neck normal.
49. Case 1. Affected. Full details in the text.

50, 51, 52, 53, 54, 55, 56, 57 and 58. Ages 18 years down to 2 months. Each one personally examined and found to have hands unaffected and no palpable cervical ribs.

59, 60, 61, 62, 63 and 64. All babies under 2. No. 63 personally seen and is quite healthy.

to note that Lewis Jones states "in two of the cases a brother has had some similar symptoms." Moreover, in my cases the wasting of the hands was not exactly symmetrical, being slightly more marked on the one side than on the other.

(2) Another objection which may be urged against the cervical ribs being the cause of the condition is that the sensory changes in my cases are very little marked. This appears to have been the case in the patients first described by Lewis Jones [6] and already referred to, and which he has since [7 and 8] proved to be due to the presence of seventh cervical ribs. Moreover, in many of the cases reported the sensory changes have been very slight; thus in the sixteen cases described by Howell, in five no loss of sensation could be discovered on examination, while in six of the other cases the loss of sensation was described as slight.

(3) The third objection is that the appearances shown in the radio-

graphs are not conclusive. In the case of Frederick Lewis there is a definite though small and sharply curved seventh cervical rib on each side, and it must be remembered that it is in these cases rather than in the cases where the cervical rib is large and prominent that muscular atrophy is found. Lewis Jones [7] states that in the cases of cervical rib, where a bony prominence can be felt with ease, the brachial plexus is usually free from any pressure, and in these cases the radiograph shows a large and straight cervical rib. In the case of Helen Lewis the radiograph shows enlarged and prominent transverse processes of the seventh cervical vertebra. But even this, in the opinion of Howell [4],

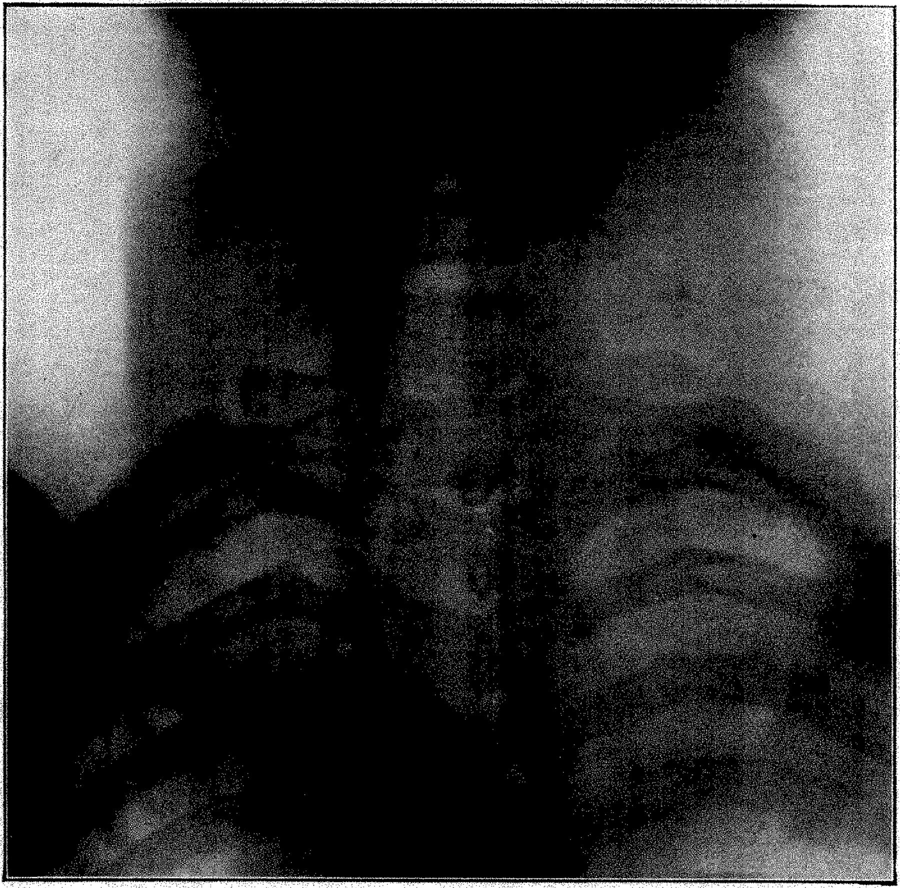


FIG. 8.

may be sufficient to cause wasting of the hand. He says: "I think that an enlarged transverse process or rudimentary rib which extends beyond the first dorsal transverse process should be regarded as a potential factor for the production of pressure symptoms." Llewellyn Phillips's [9] dissection of a cervical rib supports this view.

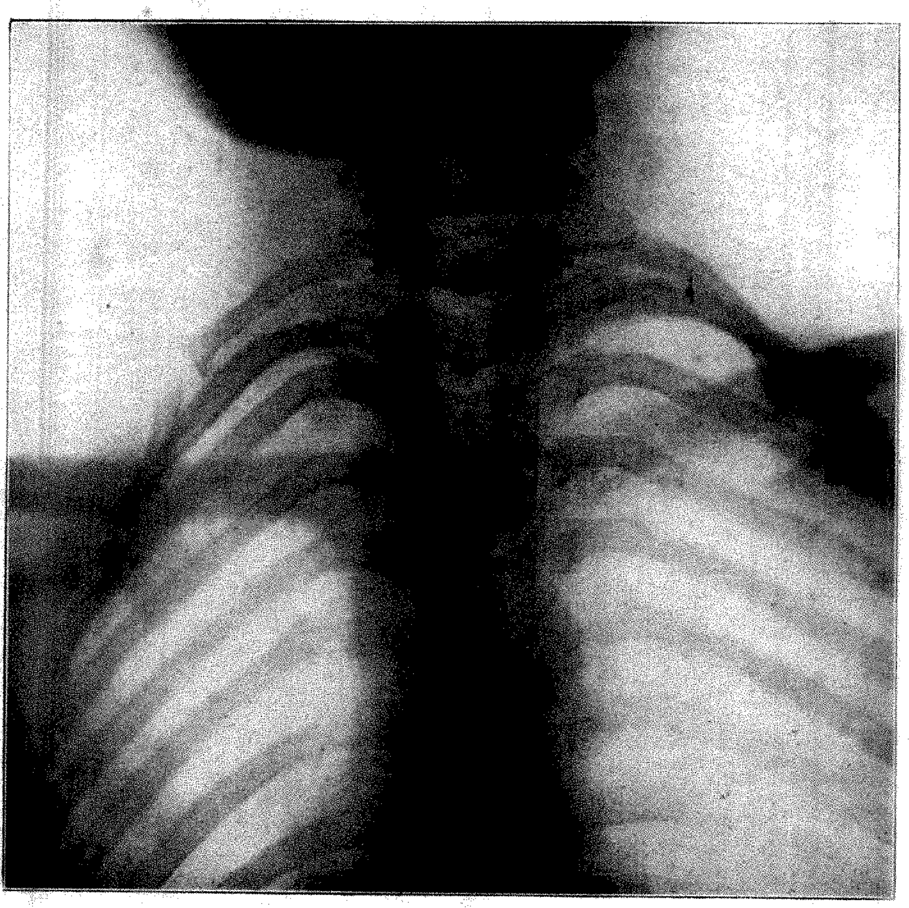


FIG. 9.

On the other hand, in favour of the condition being due to a cervical rib may be urged the early onset of the cases, occurring about the fifteenth or sixteenth year. Many of the cases of cervical rib begin to produce symptoms about this time, which coincides with the active growth and ossification of the cervical rib. Again, if the wasting of the hand was part of some general muscular condition rather than secondary to a local cause, it is probable that other muscles would have been affected; and in the two cases which I have been able to study completely, no other muscular abnormality could be discovered.

The gradual onset of the wasting and its symmetrical distribution shows that the cases were not the result of anterior poliomyelitis or examples of those cases of uniradicular palsy of the brachial plexus due to vascular lesions described by E. F. Buzzard [1]. The non-progressive nature of the affection, which continued unchanged in one of the cases until the age of 82, and the absence of marked sensory changes negatives the possibility of syringomyelia, so that it may fairly be concluded that the wasting of the hands in these cases is due to the presence of cervical ribs.

PREFIXATION OF BRACHIAL PLEXUS IN CASES OF CERVICAL RIBS.

The method by which the brachial plexus is involved has given rise to some discussion. In the large majority of cases the lowest trunk of the plexus becomes kinked as it passes over the small and strongly curved seventh cervical rib. This condition was found by Coote [2], who was the first to operate on these cases. He states that the nerve was flattened upon the upper surface of the rib, and this was also the case in the patients operated upon by Keen [5] and Thorburn [10]. Weisenstein [12], who made a careful dissection of a case, described the lowest cord of the plexus as being lifted up upon the cervical rib, and Llewellyn Phillips [9] states that in his dissection the lowest trunk of the plexus formed by the eighth cervical and first dorsal nerves crossed the cervical rib and grooved it.

In the discussion on Thorburn's [10] paper before the Royal Medico-Chirurgical Society, it was remarked that it was difficult to understand why a seventh cervical rib caused a first dorsal pain. It is hard to see why the first dorsal nerve should pass over the seventh cervical rib instead of beneath it. Much light has, however, been thrown on this question by the careful study of the brachial plexus in a case of seventh cervical rib published by Hertzlet and Keith [3]. They found that the lowest trunk of the brachial plexus passed over the seventh cervical rib, but that the brachial plexus itself was abnormally constituted. Its constitution was as follows:—

The anterior division of the fourth cervical nerve gave a large branch to that of the fifth, and from this branch was given off the phrenic nerve.

The fifth cervical anterior division joined with the branch from the fourth to form a common trunk.

The sixth cervical anterior division formed a separate trunk.

The anterior division of the seventh cervical sent a branch to the eighth cervical anterior division, and this, with a branch from the first dorsal anterior division, formed the trunk which passed over the seventh cervical rib.

The first dorsal anterior division was distributed to the first intercostal space and gave a branch to the eighth cervical.

In this case the brachial plexus is seen to be prefixed, the fourth cervical nerve taking a large share in its formation, while the first dorsal took a comparatively small share. This preparation of the plexus will explain how it is in many cases that the lowest cord of the plexus passed over the supernumerary rib.

It must be remembered that a seventh cervical rib is merely an anatomical peculiarity, the seventh cervical vertebra approaching in its characteristics to the first dorsal vertebra. This being the case it is probable that in many instances the brachial plexus is also prefixed, each segment taking on the characters of the segment immediately below it.

It is not in every case of cervical ribs, however, that the brachial plexus is prefixed, for a few cases have been recorded in which the first dorsal root passed beneath the seventh cervical rib.

Thus Thomas and Cushing [11] described compression of the lowest cord of the plexus between the first rib and a dense fibrous band passing to it from the seventh cervical rib. A similar condition was found at operation in an unpublished case of Head's. Lewis Jones [7] describes a case operated upon by Rawling, in which the cervical rib had a groove above for the eighth cervical nerve, which was sharply kinked over the anterior part of the rib. The first dorsal nerve passed under the rib and was also slightly displaced and pressed on. Both cords were of the usual size and united together a little beyond the rib. We may therefore conclude that while in many cases there may be a prefixation of the plexus, yet this is by no means always the case.

THE INHERITANCE OF CERVICAL RIBS.

Interesting as the question is, the factors concerned in the inheritance of the abnormality are extremely complicated. Briefly, in the first generation, consisting of two persons, neither was affected. In the second generation, consisting of seven persons, three males and four females, one male was affected. In the third generation, consisting of nineteen persons—seven males and twelve females—four persons were affected, two being males and two females. The inheritance took place in the case of one female through the only male affected in the second generation. One affected male was descended from an unaffected female of the second generation, while another unaffected female of the second generation gave birth to one affected male by her first husband and one affected female by her second husband. In the fourth generation, consisting of thirty persons, one male and one female were affected, the affected male being descended through an unaffected female of the second generation, while the affected female was descended from one of the affected males in the third generation.

It must, however, be remembered that many members of the fourth generation are under the age of puberty, before which time the wasting of the hands does not develop. Moreover, it seems clear that the wasting of the muscles is probably a secondary characteristic and that the primary inheritance is of the cervical ribs, which may have been present in other members of the family without producing any wasting of the muscles of the hands.

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MANIACAL-DEPRESSIVE INSANITY.

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THE term "maniacal-depressive insanity" was introduced by Kraepelin [16] in 1899 to serve as the expression of his generalization that not only the various forms of circular insanity, but also mania and melancholia (with the exception of the presenile and senile melancholias and of the melancholia which is symptomatic of dementia præcox), are merely different clinical types of one clinical entity. This generalization, though largely accepted in Germany, France and America, has hitherto not met with favour in England and Italy, and in this respect its fate resembles that of its elder compeer, dementia præcox.

Quite recently, with the general approval of Kraepelin, in whose clinic the investigation was conducted, Dreyfus [10] has further extended the connotation of "maniacal-depressive insanity" by including under it presenile melancholia. In this connection it is of interest to note that, in the sixth edition of his text-book, Kraepelin had already expressed the view that the considerably rarer presenile manias were late forms of maniacal-depressive insanity, and had thus, perhaps unwittingly, paved the way for the further inclusion of the presenile melancholias.

The following definition of maniacal-depressive insanity is given by Diefendorf [8] in his abridged translation of the seventh edition of Kraepelin's "Lehrbuch": "Manic-depressive insanity is characterized by the recurrence of groups of mental symptoms throughout the life of the individual, not leading to mental deterioration. These groups of symptoms are sufficiently defined to be termed the manic, the depressive, and the mixed phases of the disease. The chief symptoms usually appearing in the manic phase are psychomotor excitement with pressure of activity, flight of ideas, distractibility, and happy though unstable emotional attitude. In the depressive phase we expect to find psychomotor retardation, absence of spontaneous activity, dearth of ideas, and depressed emotional attitude; whilst the symptoms of the mixed phase consist of various combinations of the symptoms characteristic of both the manic and depressive phases."

As the term "maniacal-depressive insanity" implies, the fundamental characteristic of all the various types included in the group is unanimously considered, by such alienists as accept the generalization, to be an emotional or affective condition, to which such disorders of the intellect as may exist are merely secondary. The view that this emotional or affective state is conditioned by disorders of general sensation or by loss of the general sensory equilibrium, which normally occurs during healthy action of the various bodily organs (*dyscénesthésie*, Peixoto), may be considered to be merely a theoretical explanation of the emotional disturbance which is regarded as the essential feature of maniacal-depressive insanity.

The subject of maniacal-depressive insanity has recently been fully and lucidly treated by Deny and Camus [7] in their monograph, "La psychose manique-dépressive." Though primarily intended to demonstrate that the credit of initiating the generalization belongs to France rather than to Germany, their description of the manner in which the conception of maniacal-depressive insanity has been evolved is so excellent that the writer proposes to insert here its main features.

Deny and Camus divide the historical evolution of the idea of maniacal-depressive insanity into three periods :—

First period : up to the middle of the last century.

Second period : the French period, or the second half of the last century. This corresponds to the discovery of the *folie circulaire* and the *folie à double forme.*

Third period : the German period, commencing in 1899. This period is characterized by the synthesis of all the states usually described as mania and melancholic depression of many types—simple, intermittent, remittent, periodic, *folies alternés, à double forme,* circular, &c.

First period.—It had long been known that cases of mania and melancholia were subject to relapse at longer or shorter intervals, and also that these attacks might alternate and that mania might be transformed into melancholia and *vice versa.* Pinel and Esquirol merely confirmed these observations. Several authors, however—Dubuisson, Fodéré, Anceaume—were struck with the great gravity, in comparison with attacks of simple mania, of attacks of periodic and intermittent mania, and of mania complicated with melancholia. Later, in 1833, Guislain, and in 1845 Griesinger, remarked on the frequency of alternating attacks of mania and melancholia, but did not attach any especial importance to this observation. Up to the middle of the last century all authors without exception regarded mania and melancholia as two distinct entities.

Second or French period.—Pierre Falret [11], in 1851, described not an alternation of mania and melancholia separated by a more or less lengthy lucid interval, but a *forme circulaire*, consisting of a period of exaltation which alternated with a usually much longer one of depression. He, however, only described it as a distinct malady after Baillarger, in 1854, had indicated a type of insanity which is characterized by two regular periods, one of depression and one of excitement. Baillarger described this type as *folie à double forme.* He pointed out that this affection may appear as an isolated state, or may recur in an intermittent manner, or may be repeated uninterruptedly. Falret disputed the priority of Baillarger, and repeated that the *folie circulaire* consisted of three states: one of mania, one of depression, and a lucid interval. The only difference between the *folie à double forme* of Baillarger and the *folie circulaire* of Falret consists in the fact that the latter author considered the lucid interval as part of the attack, whilst the former excluded the lucid interval from it. Falret, indeed, seems to have introduced the lucid interval into his description in order to justify his term of *folie circulaire.* In brief, the malady was simultaneously described by both authors under different names. Falret, however, noted the importance of heredity, the greater frequency in the female sex, and the gravity of the prognosis. Morel [20], in 1868, saw no reason for the creation of a special type. Concerning his views Deny and Camus remark: "Et suivant encore une fois les mêmes errements qui l'avaient déjà empêché de considérer le *démence précoce* comme une entité distincte, il fit rentrer ces phénomènes d'alternance, de périodicité et d'intermittence dans la première classe de ses *Aliénations héréditaires.*" Marcé, in 1876, proposed that the term *folie à double forme* should be applied to cases of mania-melancholia in which the phases are sharply separated by a distinct lucid interval, and that the term *folie circulaire* should be reserved for cases in which the phases of mania and melancholia succeeded one another without any interruption. These designations became generally accepted. They were, however, only finally perpetuated after the publication of the articles of Foville fils in 1872 and of Ritti in 1878. At this period French alienists generally, *e.g.*, Magnan and Cullerre in 1890, Régis in 1892, Gilbert Ballet in 1894, grouped these forms, together with recurrent mania and recurrent melancholia, into a special group, that of *periodic or intermittent psychoses.*

In Germany the majority of authors accepted the views of Falret and Baillarger. One of the earliest of these, Griesinger [13], insisted on the frequency with which melancholia passes into mania, and then mania back again into melancholia. He remarks: "The disease, as a whole, thus consists of a morbid circle in which these two mental types often alternate in a regular fashion (this is the circular form which the French have discussed for some years). Other observers, and I among the number, have seen cases where regularly at a season, *e.g.*, winter, there followed a profound melancholia; then, in spring, this gave place to mania, which in its turn, in autumn, degenerated little by little into melancholia." [This description reminds one of the course at times taken by cases suffering from phthisis.]

L. Meyer, in 1874, sought to establish that the *folie à double forme* is due to trophic troubles. L. Kirn [15], in 1878, ranged the *folie circulaire* amongst the periodic psychoses. His example is followed by Krafft-Ebing, Schüle, and others.

Kraepelin, in 1893, in the fourth edition of his treatise, classed amongst incurable constitutional maladies of chronic type, by the side of systematized cases, periodic cases, of which he distinguished four groups: delirious (*i.e.*, delusional), maniacal, circular and depressive. This classification resembles that in use in France during the same period.

Third or German period.—In 1899 Kraepelin [16], in the sixth edition of his treatise, introduced a new classification. He observed that the more or less regular repetition and alternation of attacks of mania and melancholia are not characteristics of sufficient importance to constitute a basis for separate types. He showed in effect that the psychoses called intermittent, periodic, circular, *à double forme*, alternating, &c., all show the same mode of evolution, and that it is more logical to consider all these states as the manifestations and the equivalents of one fundamental malady, *maniacal-depressive insanity.* He noted that he had never seen a single case of mania which had not been followed by relapse, and also that it is impossible to distinguish between cases of simple mania and cases of relapsing and intermittent mania, and therefore he considered that classical mania ought to be removed from the list of mental maladies. This "mania" had previously been referred to by Pinel and Esquirol and had been ostracized by the two Falrets and by Morel. Kraepelin considered it convenient to describe apart those cases of melancholia which occur at the period of involution and in senility. He included melancholias of youth and of maturity, which always relapse or alternate with attacks of mania, under maniacal-depressive insanity, unless they should be symptomatic of dementia præcox.

Magnan [17], in 1890, had already grouped several of these forms under the term "intermittent insanities," but he excluded from this class degenerative maniacal exaltation and melancholic depression, and at the same time simple mania and simple melancholia. Deny and Camus therefore remark that Kraepelin, some years later, completed the essay at reconstruction initiated by Magnan.

These authors then produce further evidence pointing to the undesirability of regarding mania as a distinct clinical entity. Gilbert Ballet and Régis so regard it, but whilst the former indicates symptomatological differences between the simple and the intermittent forms of both mania and melancholia, the latter [23] considers such to be non-existent.

Erp Taalman, in 1897, stated that, of 107 cases of mania, in only four cases was the diagnosis confirmed by the course of the disease. Otto Hinrichsen similarly remarked that the proportion of cures in cases of mania dating for more than twenty years is only 4·7 per cent. Weygandt and also Thomsen follow Kraepelin, and the latter goes even further and throws doubt on the existence of periodic mania, at least in a state of purity, because it is always followed by a more or less marked period of depression. He thus includes periodic mania under *folie à double forme*, an opinion already formulated by Griesinger. In Belgium, Claus, in 1903, stated that pure cases of mania and melancholia are rare. Lambranzi and Perazzolo, in 1906, stated the same opinion, which had already been defended, in 1899, by Finzi and by Vedrani.

From these facts Deny and Camus conclude that the line traced by the older authors between simple mania and melancholia on the one hand, and periodic mania and melancholia on the other, is purely conventional, and that Kraepelin is right in placing the former in the old group of periodic psychoses, now called *maniacal-depressive insanity*.

Bianchi, Tanzi, Francoda Rocha, and others, however, include under maniacal-depressive insanity simply the double and circular forms, both of which show phases of excitement and depression; and at first sight it is not clear in what way intermittent and periodic forms of mania and melancholia can be included under the designation. Deny and Camus produce the following arguments in favour of the inclusion of the latter: Pure and unmixed periodic mania and melancholia are quite exceptional. The more often one observes two, three, and four attacks of mania, the more often one notices that an attack of depression replaces the expected one of mania (intermittent mania of irregular type [Arnaud]). Conversely, one sees a series of attacks of melancholia interrupted from time to time by an attack of mania (intermittent melancholia of irregular type of the French authors). They thus consider that periodic manias and melancholias are really *abortive* examples of the double form, in which one of the phases is unrecognized. "In other words, attacks of intermittent mania are in reality attacks of mania-melancholia, but with a maniacal preponderance" (p. 18), and *vice versa*. They thus confirm the observations of Rogues de Fursac [12], who, in 1903, stated: "Each attack of mania or of melancholia thus contains in germ the elements both of excitement and of depression. An attack of *folie circulaire* becomes thus the prototype from which are derived all the others." Afranio Peixoto [21] holds the same view (1905). Gilbert Ballet [2], in 1902, suggested that circularity is a functional law of the nervous system, that we are all to some extent *circulaires*, and that the pathological state, which constitutes periodic insanity in its most characteristic form, is simply an exaggeration or amplification of the manner of bearing which is habitual to all of us. Deny and Camus accept this view and argue in favour of it. They point out that mixed states exist, described by Kraepelin but previously indicated by Guislain, in which excitement and depression coexist, are mixed, and are entangled, instead of *succeeding* as in the double form. They remark that, in spite of their opposed characters, the phenomena of excitement and of depression have the same origin and arise from the same psycho-pathological mechanism. They finally state: "But putting to one side these last two arguments . . . one can already conclude from the preceding considerations that the term maniacal-depressive insanity is doubly legitimate, since the association of excitement and depression is true, not only for the total series of attacks which constitute this psychosis, but still more so for each of these attacks when it is separately considered" (p. 20).

They then define maniacal-depressive insanity as "a constitutional psychosis, which is essentially hereditary, and is characterized by the repetition, the alternation, the juxtaposition, or the coexistence of states of excitement and of depression" (p. 21). They remark that this type of insanity can be differentiated only by its symptomatology and its evolution, and that it is impossible to assign to it a special etiology or to attach to it anatomical lesions. They regard it as "a simple *clinical entity*, which takes a natural place by the side of chronic systematized insanity, in the group of *constitutional psychoses*, similar to the natural position of dementia præcox by the side of general paralysis, in the group of *accidental psychoses*."

It should be remarked that these authors follow Kraepelin in specifically excluding the melancholia of involution from maniacal-depressive insanity.

The conception of maniacal-depressive insanity, as has already been stated, has finally been still further elaborated by G. L. Dreyfus [10], who, in his monograph entitled "Die Melancholie ein Zustandsbild des manisch-depressiven Irreseins" (1907), has proposed the inclusion of the melancholia of involution.

After a useful historical description of the evolution of the modern conception of melancholia, this author refers in detail to the views of Kraepelin [16] on melancholia. He notes how, in the different editions of Kraepelin's treatise, the application of the term "melancholia" is gradually more and more restricted, until in the fifth edition (1896) this term is applied by Kraepelin to a typical disease of the involution period of life which represents a transition to the senile mental disorders. The chief differences noted by Kraepelin between melancholia and maniacal-depressive insanity are the absence of psychomotor inhibition in the former and the tendency of this form to end in dementia. Kraepelin remarks that the depressive stage of maniacal-depressive insanity may exactly resemble presenile melancholia, and that the fact of melancholia occurring only once in a lifetime cannot be regarded as a ground for denying its relationship to circular insanity, since in the involution psychoses depressive states frequently recur. He, however, regards it as significant that a single attack of melancholia at the presenile period is common, but a single attack of mania is far rarer. Whilst, therefore, Kraepelin includes under the involution psychoses melancholia, presenile delusional insanity, and senile dementia, he considers presenile mania to be a late form of maniacal-depressive insanity.

Dreyfus, as the result of an exhaustive study of the material available at the Heidelberg clinic, has decided that these differential criteria lose their significance when cases of presenile melancholia are followed throughout their entire course. He states that it is common to meet in cases of presenile melancholia (1) with the qualities of mood which characterize the depressive stage of circular insanity, (2) with various kinds of partial inhibition, and (3) with variations and oscillations from day to day, &c., which are reminiscent of circular insanity. For the purposes of his investigation he has minutely studied the previous and also the subsequent histories of melancholic cases, with especial regard to the slight symptoms which occur from time to time during the periods when the patient is for practical purposes well and sane. He in this connection remarks on the protracted course of the disease, of which the greater part is usually passed outside an asylum. With regard to the question of dementia in presenile melancholia, Dreyfus considers that it is less common than Kraepelin stated, and that when present it is due to cerebral arteriosclerosis.

As an indication of the way in which the proposition of Dreyfus has for a long time been foreshadowed at Heidelberg may be reproduced here the following figures, which indicate how, during the years 1892—1906 the number of cases diagnosed as "melancholia" has steadily decreased, although the number of annual admissions has more than doubled during this period:—

Year	Diagnosis of Melancholia, or "Depressive Wahnsinn"	Erroneous in	Total Admissions
1892	11	7	258
1893	10	1	240
1894	11	2	251
1895	12	2	254
1896	7	1	215
1897	7	1	280
1898	4	2	325
1899	4	2	367
1900	2	1	383
1901	3	0	366
1902	1	0	400
1903	5	1	520
1904	4	4	549
1905	0	1	531
1906	0	0	579
Total	81	25	5,518

As Kraepelin, in his preface to the volume, expresses his general agreement with the contention of Dreyfus, it may therefore be presumed that presenile melancholia will in the future be included under the maniacal-depressive group.

The above general review of maniacal-depressive insanity will now be concluded with a short reference to certain etiological and clinical characteristics.

Kraepelin considers that maniacal-depressive insanity is one of the most prominent forms of mental disease, and that it includes from 12 to 20 per cent. of admissions. Deny and Camus find the similar percentage of 17·5 at the Salpêtrière, and Peixoto the much smaller percentage of 6·6 at Rio de Janeiro, where part of the asylum population is coloured.

Heredity figures as the prominent cause, and the various authors give percentages varying from 70—80 to 90. Relatives have often suffered from the same form of disease, and a defective constitutional basis, amounting in some cases to imbecility, is stated to be common.

About two-thirds of the cases are of the female sex, a fact first noted by Falret.

Kraepelin states that the first attack occurs before the age of 25 in two-thirds of the cases, and after the age of 40 in less than 10 per cent.; and that the onset may be as early as 10 or as late as 70.

Some difference of opinion (Deny and Camus) exists with regard to the mental condition of the patients during the "lucid" intervals. The majority of the French alienists follow Falret and Baillarger in considering that during the intervals the patient is sane, and has returned to his "normal" state. Krafft-Ebing, Schüle, and Kraepelin are of the opinion that during the intervals the patients as a rule exhibit such traces of the malady as distrust, increased emotivity, decreased energy and capacity for work, &c., and Dreyfus [10] largely bases his inclusion of presenile melancholia in the maniacal-depressive group on the existence of such symptoms during the course of the former disease. Magnan explains this divergence of opinion on the ground that the maniacal-depressive group as now constituted includes many degenerates suffering from mental debility and instability. Arnaud believes that lucid intervals of many months, and especially of years, represent a return to the normal, whilst such intervals, when lasting for days or weeks only, are of the nature of amelioration rather than of cessation of symptoms. Deny and Camus express a guarded opinion, though they are inclined to think on the whole that the German view is the more correct.

The above description of maniacal-depressive insanity, which is largely based on the monographs of Deny and Camus [7] and of Dreyfus [10], sufficiently indicates the nature of this generalization. The writer therefore does not propose to refer here to the numerous recent publications which deal with special details of symptomatology, &c. A paper by Albrecht [1] on the incidence of arteriosclerosis may, however, be mentioned, owing to its bearing on the views of Dreyfus, with regard to the development of dementia in presenile melancholia. Albrecht finds that 30 per cent. of cases of maniacal-depressive insanity exhibit this morbid appearance, whereas it occurs in but 40 per cent. of alcoholics and but 10 per cent. of cases of dementia præcox. He is of the opinion that in the relatively rare elderly subjects, arteriosclerosis may precipitate the onset of mental symptoms, whereas in the larger number of cases the frequent variations in arterial tension which occur may be a cause of the arteriosclerosis.

Whilst the subject of maniacal-depressive insanity now possesses quite a respectable literature, the supporters of Kraepelin are chiefly drawn from Germany, France and America. Mendel [18], however, though he employs the term maniacal-depressive insanity, includes recurrent and periodic mania under mania, and periodic and remittent melancholia under melancholia, and groups other recurrent cases under the term "circular psychosis," after Hoche [14] and Pilcz [22].

Bianchi [3] regards pure mania as relatively rare (2 to 3 per cent. of admissions), and describes pure and periodic mania together. He considers melancholia to be more common than mania, and groups periodic melancholia with it. His "melancholia" somewhat resembles the melancholia of Kraepelin. Under the term "maniacal-depressive insanity" he includes maniacal-depressive, mixed, and circular forms.

The conception of maniacal-depressive insanity has hitherto not obtained any foothold in England. That this is due neither to insular conservatism nor to lack of interest in the study of mental diseases the writer, however, hopes to make clear during the remaining portion of this paper.

Clouston [5], in his chapter on "states of alternation, periodicity, remission and relapse in mental diseases," draws certain general conclusions concerning these states which well illustrate the broad conception of insanity held by the more prominent of English alienists. It is possible, in fact, that in the future foreign psychiatrists, by gradually increasing the breadth of their generalizations, will end where English psychiatrists have begun, by recognizing the unity of mental diseases. The remarks of Clouston are of sufficient importance to deserve quotation in full:—

"Looking at all those facts and considerations, therefore, I come to these conclusions: that periodicity, or a tendency to alternations of elevation and depression, is a very common characteristic of mental diseases; that it is much more marked where they are very hereditary than in any other cases; that it is more common in youth, puberty, and adolescence than at other periods; that it is in its essential nature the exaggerated or perverted physiological diurnal, menstrual, sexual, or seasonal periodicities of the healthy brain; that the cases that have been called *folie circulaire*, katatonia, &c., are merely typical or exaggerated or more continuous examples of pathological periodicity. Another remarkable fact about the typical form of alternating insanity is, that by far the greater number of patients who suffered from it were persons of education, and far more than a due proportion of them were members of old families. I never met with a fine case in a person whose own brain and whose ancestors' brains had been uneducated. It seems to me that the tendency to alternation of mental condition, to energize at one time with morbid hurry and then with morbid slackness, is one of the forms of brain instability which specially results from too much 'pureness of blood' or from the heredity of many generations of gentlefolks, all of whose brains had been more or less educated. Possibly it is one of the modes by which Nature brings that kind of stock that has become degenerate by over-cultivation of the brain for many generations to an end. Real work can sometimes be done during the sane periods. D.D. has done some literary work in the intervals of his attacks, for the twenty-six years he has been ill."

Savage [24], in his Lumleian Lectures, expresses his views with regard to insanity as follows: "I still believe that what Hughlings Jackson said many years ago is true, viz., that we physicians connected with insanity resemble gardeners rather than botanists; that the fact must be recognized that we classify for convenience rather than on a scientific basis, because in point of fact no such basis, or finality of mode, has as yet been discovered. . . . The conclusion, then, follows that, there being no definite entity of insanity, there can be no one comprehensive definition of it, and that the person is sane or insane in relation to his own standard and not to any existent arbitrary one, except the conventional arbitrament of civilization. And as this varies, the truth of my former remark becomes evident, that what is reasonable conduct in one man under certain conditions may be plain madness in another differently situated. I often think of a splendid young animal whom I saw—the son of a distinguished father, who rightly judged his son to be an anachronism, out of place in fact; and considered that he would have made a fine knight in the Middle Ages, and perhaps even now might make a good cowboy in America." With regard to mental degenerates he remarks: "They generally come of insane stock and tend to transmit their neurosis, in one form or another, to their descendants. They are more liable than others to break down under slight stresses;

ceteris paribus, their neuroses appear at the critical periods of life, such as adolescence, puberty, and, in the case of women, with child-bearing and the menopause. These patients show a special liability to relapse after recovery, and, as a sequence, to establish a habit of recurring mental disorder—mania, melancholia, as the case may be. This morbid habit may become more and more organized and pass into regular circular insanity."

Savage and Goodall [25] describe recurrent melancholia and recurrent mania under chronic insanity, and make a brief reference to maniacal-depressive insanity in the following terms: "In the present state of knowledge there would not appear to be sufficient justification for abandoning the older method of classification and for regarding mania and melancholia as mere phases of one disease."

Mercier [19] thus states his views on the nature of insanity: "We have to recognize that in insanity there are not only those disorders of the object-consciousness—those delusions, doubts, obsessions, and so forth, which are described in the text-books—not only is there often an alteration in the feeling of well being—a melancholy or an elation—which is sometimes recognized to belong to the subject; but there is, in addition, a more profound and intimate change in the subject itself; a change in the mode of activity; a change in the capacities or possibilities of acting; a change in the direction of action; a change, in short, of the very self; which renders the insane man a different person from his sane self." As would be expected, therefore, Mercier recognizes "recurrent insanity" in his text-book, and makes no reference to maniacal-depressive insanity. He indicates the recurrent type of insanity described by foreign writers under "dementia præcox" in the following terms: "There is a variety of circular insanity in which the period of depression is replaced by a period of stupor, usually of the resistive type, and to this variety the name of 'katatonia' has been given."

Drapes [9], in a recent paper on the "Unity of Insanity," remarks: "The term 'manic-depressive' or 'maniacal-depressive,' which has come into vogue of late years, as denoting a special form of insanity, although not of any value if it is meant to imply some variety not yet described, is yet of some value as indicating an acknowledgment of the fact—hitherto ignored in all schemes of classification—that there is such a thing as mixed insanity. In reality such cases are merely those which constitute a large proportion of ordinary chronic insanity. We might extend this nomenclature still further and describe cases as manic-depressive-stuporous, and even manic-depressive-stuporous-delusional-demented, if we want to give a more complete clinical description of quite a number of cases. The fact is, these fanciful so-called 'varieties' are all nothing but clinical descriptions of the one disordered mental condition, insanity, while it is passing through certain more or less transitory, or a succession of transitory, stages, and to attach a separate style and title to such temporary conditions, or to any combination of them, is nothing but to create confusion in our conception of insanity."

Maurice Craig [6], in his recent text-book, retains the terms recurrent mania, recurrent melancholia and *folie circulaire.* He remarks: "The student should clearly understand that such terms as mania and melancholia merely designate *groups of symptoms*"; and "The writer fully agrees with much that Kraepelin has stated, but the distinction that the latter makes in dividing his cases into groups is almost too fine for teaching purposes."

Whilst welcoming the generalization of maniacal-depressive insanity, in so far as it indicates a tendency to recognize that a large group of cases of insanity are of developmental rather than of obscure or accidental origin, the writer cannot regard it as indicative of a special type of mental disease. He would quote Gilbert Ballet against himself, and remark that we are all more or less "circulaires," whether we are sane or insane. We are circulars when sane; we are circulars when insane; we are circulars whether sane or insane, in cases where we are at one time sane and become at another time insane. Circularity is not insanity, but depends on periodic modifications in the functional activity of the cerebrum, whether this be working normally (sanity) or abnormally (insanity). The emotional tone of the sane varies in degree and kind according to circumstances. It is a quality rather than a special division of psychic function. The emotional tone of the insane also varies in degree and kind, but, except in the early stages of acute attacks, the change is always in the direction of decrease or loss, however much an increase of emotional tone may be suggested by the psychomotor symptomatology which is exhibited. Lest this statement should be misunderstood, it is perhaps desirable to remark that certain "chronic lunatics" are only permanently insane in the legal sense.

The space at his disposal not permitting of any discussion of the theory of the emotions, the writer thus merely indicates his opinion that the emotive or affective states, which are unanimously regarded as the essential characteristics of maniacal-depressive insanity, form an entirely inadequate basis on which to erect an important group of mental diseases. As he has remarked in his series of articles on "Amentia and Dementia" [4], he considers insanity to be one disease, of which the various clinical "forms" depend, on the one hand, on various grades and types of cerebral subevolution, from idiocy up to the "normal" (amentia), and, on the other, on various grades and types of cerebral dissolution and involution (dementia). The more marked the degree of amentia, the less, in general, is the tendency to dementia, though the cortical neurones of even the idiot may undergo involution, and those of even the "normal" individual may suffer either dissolution or involution.

On this view the miscellaneous cases included under maniacal-depressive insanity are merely certain examples of such grades of amentia as preclude the application of sufficient "stress" to determine cerebral dissolution, for the cerebra of these cases, regarded as machines, so readily become deranged that asylum *régime* and the consequent absence of "stress" ensue before permanent injury to the cortical neurones results.

In such cases of mental disease, and also in many others, the functional disturbance of the cerebrum is of a relatively low order, and, considered from the general aspect, involves: (1) decreased action of the higher and latest evolved cerebral functions of control and coördination, which results in abnormalities of *immediate* cerebral activity, and in consequent emotional and psychomotor disturbances of various kinds, and (2) (in the more degenerate types) generally aberrant and subnormal cerebral activity. In other words, the writer considers that the cerebrum, as a machine, is working in a defective manner, and that all the "functions of mind," and not merely the emotions, are involved. This abnormal form of cerebral activity is, however, of an *immediate* type, and does not to any extent involve the revivification of complex and time-related portions of the subconscious content of mind, as often occurs in, *e.g.*, hysteria, epilepsy and paranoia.

Such examples (which include the whole maniacal-depressive group) are roughly classified by the writer into two groups: (1) Cases which at times may be regarded as "sane" or "normal," and (2) cases of greater cerebral degeneracy, which are never really so.

The former group includes all types of recurrent case, whether these be still capable of "recovery" or have become permanently insane asylum inmates. About two-thirds are of the female sex.

The latter includes the following general types: (*a*) "Moral" cases; (*b*) simple "emotional" chronic mania; (*c*) chronic mania with incoherence and delusions; and (*d*) "cranks" and asylum curiosities. About three-quarters are of the female sex, the proportions varying from 8 to 1 in (*b*) to about 3 to 2 in (*a*) and (*d*).

The cases in these clinical subclasses show, respectively, the following prominent characteristics:—

(*a*) *Alteration of moral sense*, with a tendency to do desperate things, *e.g.*, to commit suicide or even homicide, to perform acts of self-injury or self-mutilation, to strike, smash or destroy, to irritate intensely those around them, to be sexually inclined in a normal or abnormal direction, &c.

(*b*) *Alteration of emotional and intellectual control*, *e.g.*, exuberance, instability, vanity, garrulity, childishness, and often violence, treachery, and destructiveness. The younger and adult patients usually display a more or less marked loss of control over the emotions and instincts. The older patients differ from these in the fact that the loss of control affects chiefly the intellectual functions. Their association of ideas is normal, except for its extreme rapidity and complexity. They talk continuously whenever a listener can be found, and they are frequently inconsequent and show a marked tendency to parenthesis during their descriptions.

(*c*) *Rapid and uncontrolled association of ideas*, with delusions of grandeur, which may or may not coexist with or follow delusions of persecution. These cases form a half-way house between subclasses (*b*) and (*d*), and shade gradually into each of these. They differ from the former in being, on the whole, less troublesome, and in showing an apparently complete incoherence in their association of ideas, and from the latter in the fact that their ideation is simply rapid and uncontrolled rather than grotesque or symbolical, and resulting in erratic and eccentric conduct.

(*d*) *Stereotyped, symbolical, or grotesque association of ideas*, which leads to weird actions and eccentric general behaviour. These cases are extremely conceited, vain, and grandiose. They are of many types, and may be simply asylum "show-birds," or may possess considerable artistic or intellectual talent. As a class, these cases only differ from certain "sane" individuals in the absurd and grotesque extremes to which they carry their ideas and their resulting behaviour and actions; and their stereotypism, which often suggests dementia, also only differs in degree from the stereotypism and prejudice which are often seen in the "cranks" of the outside world.

It appears to the writer that the cases of mental disease grouped under the term "maniacal-depressive insanity" all fall naturally into the above larger division. Experience has convinced him that the greater the degree of cerebral degeneracy the less evident is depression as a symptom or a phase of symptomatology, and *vice versa.* This emotional disturbance is therefore pre-eminently a characteristic of the former (recurrent) group, and is of subordinate importance, and often entirely absent, in the case of the latter (permanent) group. He has, in fact, often noted that cases which at one time were "circular" have later on partially or entirely lost the depressive phase, and he is disposed to regard this phase, when post-maniacal, as to some extent indicative of a still possible return to the "normal." He therefore welcomes the recent inclusion of presenile melancholia in maniacal-depressive insanity, for, in conformity with the above opinion, he has long been convinced that the capacity to develop a prolonged attack of melancholia is indicative of what is practically the mildest grade of cerebral insufficiency and of the onset in the majority of such cases of (senile or presenile) cerebral involution.

He would remark that any of the cases included in the above division of amentia may suffer from the accessory symptomatology of mental confusion, with disorientation and sensory symptoms, as the result of alcoholic or other form of intoxication, or of degeneration of the cerebral arteries; and from the latter aspect he partially agrees with Kraepelin, Dreyfus and others who consider arteriosclerosis to be the cause of the dementia which develops in many cases of chronic melancholia.

With regard to the recurrent types of insanity generally (*i.e.*, those recurrent types which do not develop dementia) he would again draw attention to the remark of Clouston: "Another remarkable fact about the typical form of alternating insanity is, that by far the greater number of patients who suffered from it were persons of education, and far more than a due proportion of them were members of old families. I never met with a fine case in a person whose brain and whose ancestors' brains had been uneducated." The possessor of one of the finest intellects the writer has met with was insane and in a condition of permanent and uncontrolled exaltation of cerebral function. He had earlier in life been a university professor, and a near relative had attained to eminence. This individual might be regarded as the owner of a cerebrum which was too elaborately developed to be properly controlled in its existing stage of evolution. Such brains, working under proper control, may be common in the far distant future. From the "normal" aspect it is well known that fine pieces of work have been rapidly done whilst their authors were so intensely absorbed as to be practically in a condition of general cerebral exaltation or mild "sane" mania, for which, however, the subjects had afterwards to suffer in recuperative depression of the cerebral functions. The higher types of recurrent insanity thus grade upwards towards the cerebral hyper-activity of genius, whilst the lower types grade downwards into the analogous cases who are never really sane, although they may legally pass as such.

The writer is unable to regard mania and melancholic depression as simple and opposite motive states, though mere excitement and depression may be such. Mania, whilst at times outwardly indicative of general exaltation of cerebral function, is more often a sign of decreased action of the higher controlling and latest evolved portion of the cerebrum. Melancholia, on the other hand, whilst it is indicative at times of recuperative general depression of cerebral function, or of impending loss of higher cerebral control, is more often a sign of the onset of permanent general depression of the cerebral functions, and is thus the objective evidence of impending or developing (presenile) involution of the cortical neurones. Mania is thus of less grave prognostic import than is melancholic depression, and this statement is in agreement with general clinical experience and practice; for, alcoholic cases being excluded, patients with mania are more readily discharged "recovered" than those who suffer from melancholia (quite apart from the question of suicide).

As will have been gathered from the above remarks, the writer therefore considers that the maniacal-depressive generalization is untenable as a description of a special kind of mental disease, although he welcomes it as indicative of a tendency to decrease the number of "mental diseases," and thereby to make a further advance towards the conception that insanity is one disease, which is due on the one hand to various grades and forms of cerebral subevolution, and on the other to various grades and forms of cerebral involution and dissolution.

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Die Polyneuritischen Psychosen, by ALBERT KNAPP. (Wiesbaden: J. F. Bergmann, 1906.)

ALTHOUGH Bonhoeffer's "Akute Geisteskrankheiten der Gewohnheitstrinker" is still the most important and generally useful of works dealing with polyneuritic psychosis, this well-written little book of Dr. Knapp's is distinctly valuable as a supplement to it. Of its 140 pages, nearly ninety are devoted to a report of eight selected atypical cases, and the remainder to a general description of polyneuritic disorders, somewhat on the lines of a text-book.

The question when a psychosis may rightly be termed polyneuritic is answered thus (p. 116): "Doubtless when marked neuritic phenomena are combined with the amnesic symptom-complex. But it is generally recognized that in Korsakow's psychosis the neuritic phenomena may be in the background or may quite elude observation, and that the polyneuritic virus may attack the brain exclusively. . . . Just as the neuritic phenomena may be only slightly indicated, so, too, in many cases, the Korsakow symptom-complex is not present in its full development."

In his general description Knapp tells us nothing new about the Korsakow symptom-complex itself; he is content with a bare enumeration of its constituent features. In his reports of cases also he in this respect gives just sufficient facts only to indicate that this symptom-complex was present. He devotes his attention to the other very varied phenomena which may accompany it. Here are no results of that psychological analysis and experiment for which polyneuritic psychosis offers a field hardly to be equalled by any other pathological condition with which we are acquainted; but instead we are given an admirably pictorial account of a great variety of mental symptoms, familiar in themselves, but not commonly recognized as apt to occur in conjunction with polyneuritic psychosis. From this standpoint Knapp recognizes the following forms of polyneuritic psychosis:—Delirious, stuporose, demential, hallucinatory (systematized and unsystematized), and paranoic forms; *Angstzustände;* expansive, maniacal, and melancholic forms; polyneuritic motility psychoses; and cases with rarer mental anomalies. The maniacal form is rare, and unrecorded before Knapp's fifth case here; but the writer of this notice has had under his observation a case which might well enough come under this head, as it presented marked *Ideenflucht*, with rhyming and clang-association, and a mood characterized by boisterous hilarity rapidly alternating with anger. Knapp's list may perhaps give fresh discouragement to those who look for a systematic classification of mental diseases on a basis of symptomatology.

The very interesting and important cerebral focal symptoms (aphasic, agnostic, and the like) are well discussed in a general way, but not in detail. In the section on bodily symptoms, especially those referred to peripheral nerves, a number of anomalies are discussed, such as the occasional occurrence of exaggerated knee-jerks with hypotonus. But sluggishness or rigidity of pupils to light is perhaps hardly so common as the wording of Knapp's remarks might lead one to suppose.

On the question of etiology, Knapp is not with those who regard polyneuritic psychosis as an essentially alcoholic disorder. In six of his eight selected cases he somewhat confidently excludes alcohol; and he says it is surely no accident that all polyneuritic psychoses of atypical course without alcoholic etiology have occurred in women, and he lays stress on menstrual disorders and the climacteric; he discusses also the various infections and toxæmias. Of course he agrees with Bonhoeffer and many others that cases of polyneuritic psychosis often begin with a condition indistinguishable from delirium tremens, but he goes further and says this may happen even in non-alcoholic cases. We look in vain for any mention of the remarkable curve of seasonal incidence of polyneuritic psychosis, which attains its maximum near the middle of the second half of the year, and thus resembles an exaggerated form of the curve for delirium tremens.

The book is sober, concise, and commendably quotable, its statements being put as positively as possible. Dr. Knapp has, on the whole, successfully contrived to give a general view with as little resumption as possible of old knowledge, and as complete a presentation as possible of what is new and original.

S. J. Cole.

PUBLICATIONS RECENTLY RECEIVED.

[*Notes on a book under this heading do not preclude a subsequent review.*]

Vorlesungen über den Bau der nervösen Zentralorgane des Menschen und der Tiere. Zweiter Band: *Vergleichende Anatomie des Gehirns.* Von LUDWIG EDINGER. S. 334. Leipzig: Vogel, 1908.

The seventh edition of this remarkable book should be in the hands of every neurologist. It is easy to read, luminous, and illustrated with 283 figures. The author is to be congratulated on the character of his work and on his power of exposition.

The Science and Philosophy of the Organism. The Gifford Lectures, delivered before the University of Aberdeen in the year 1907. By HANS DRIESCH, Ph.D. Pp. 329. London: Black, 1908.

This volume is concerned with the chief results of analytical biology, morphogenesis, adaptation and inheritance. The author then passes to the principles of schematics, the theory of descent, and the logic of history. A most valuable work, dealing with the influence of present biological theories upon philosophic thought.

Diseases of the Spinal Cord. By R. T. WILLIAMSON, M.D. Pp. 432. With 183 illustrations and seven plates. London: Henry Frowde and Hodder & Stoughton, 1908.

This work is put together from a series of lectures by the author on a subject in which he has long been an authority. The pathological descriptions are unusually complete, and are illustrated with excellent plates. The clinical aspect is dealt with adequately. The book is admirably printed, and will be of use to the physician interested in the pathology of the cord-diseases which come under his notice.

Nervöse Angstzustände und ihre Behandlung. Von Dr. WILHELM STEKEL. S. 315. Berlin and Vienna: Wibau & Schwarzenberg, 1908.

A full account of those neuroses associated with fear, all those phenomena to which the name "phobias" has been given. The book contains a large number of clinical observations and is well worthy of study alike by the general physician and neurologist.

Transactions of the Ophthalmological Society. Vol. xxviii. Fasc. ii. London: Churchill, 1908. [These *Transcations* are now issued in three parts annually, each of which costs 4s.]

This number contains a paper on "Optic Neuritis in Cerebral Tumours," by Mr Paton, based on observations made at the National Hospital. He concludes that there is no evidence to show that the changes in the disc are due to meningitis or to inflammation descending the nerve trunk; nor is it caused by pressure on the nerve sheath or local vasomotor changes. He prefers to believe optic neuritis with tumours of the brain is a local manifestation of a generalized œdema of the cerebral tissues. This paper was followed by an animated discussion.

Nursing the Insane. By CLARA BARRUS, M.D. Pp. 409. New York Macmillan, 1908.

An excellent attempt to deal with a difficult subject. Care of the insane is treated not as a modified form of hospital nursing, but as worthy of independent study. The directions are clear and the index complete.

Education, Personality and Crime. By ALBERT WILSON, M.D. Pp. 296. London: Greening, 1908.

A popular book in which the work of modern neurologists, psychologists and alienists is dealt with superficially. It is full of crude generalizations from complex facts.

Writers of "Original Articles and Clinical Cases" are supplied free of charge with 50 copies reprinted in the form in which the paper stands in the pages of "Brain." If reprints are required in pamphlet form, with wrapper, title-page, &c., and re-numbered pages, they must be ordered, at the expense of the writers, from Messrs. BALE, SONS & DANIELSSON, Ltd., 83-91, Great Titchfield Street, London, W.

Members of the Neurological Section of the Royal Society of Medicine can obtain the Index of "Brain" for the Volumes I. to XXIII. inclusive, that is, from its commencement to the end of 1900, from Messrs. MACMILLAN & CO., Ltd., St. Martin's Street, London, W.C., at the price of 6s. 6d., post free.

To those who are not members of the Neurological Section of the Royal Society of Medicine the price is 8s. 6d. net, and the volume may be obtained through any bookseller.

EDITOR.

[NOVEMBER, 1908.]

BRAIN.

PART III., 1908.

Original Articles and Clinical Cases.

A HUMAN EXPERIMENT IN NERVE DIVISION.

BY W. H. R. RIVERS, M.D., F.R.S.,
Fellow of St. John's College, Cambridge;

AND

HENRY HEAD, M.D., F.R.S.,
Physician to the London Hospital.

CHAPTER I.—HISTORY OF THE CASE.
CHAPTER II.—METHODS OF EXAMINATION.
CHAPTER III.—THE PHENOMENA OF DEEP SENSIBILITY
CHAPTER IV.—PROTOPATHIC SENSIBILITY.
  Section 1.—Borders of Dissociated Sensibility.
  Section 2.—Pain.
  Section 3.—Heat and Cold.
  Section 4.—Hair-Sensibility.
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CHAPTER V.—EPICRITIC SENSIBILITY.
  Section 1.—Tactile Sensibility.
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CHAPTER IX.—INTENSITY.
CHAPTER X.—PUNCTATE SENSIBILITY.
  Section 1.—Heat- and Cold-Spots.
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CHAPTER XI.—GENERAL THEORETICAL CONCLUSIONS.
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CHAPTER I.—HISTORY OF THE CASE.

IT had long been recognized that the consequences of injury to a peripheral nerve could not be adequately explained on any accepted theory of its structure and function. In 1901, Dr. Head and Mr. Sherren therefore determined to make a systematic examination of the patients attending the London Hospital for some nerve injury. The hospital patient is frequently an admirable subject for sensory experiments; at his best he answers "Yes" and "No" with certainty, and is commendably steady under the fatigue of control experiments. Moreover, the number of patients, who come to the London Hospital for such injuries, is so large that it is possible to eliminate entirely those who are found to be untrustworthy in consequence of misuse of alcohol or other causes.

Most of the main facts of nerve distribution and recovery of sensation can be elicited from a study of hospital patients by means of simple tests requiring no undue expenditure of time. But such patients can tell little or nothing of the nature of their sensations, and the time they are able, or willing, to give is insufficient for elaborate psycho-physical testing.

It soon became obvious that many observed facts would remain inexplicable without experimentation carried out more carefully and for a longer period than was possible with a patient, however willing, whose ultimate object in submitting himself to observation is the cure of his disease. For instance, an examination of the part played by heat- and cold-spots in the return of sensation was impossible under clinical conditions.

It is also unwise to demand any but the simplest introspection from patients, to whatever class they may belong. This side of the investigation was, therefore, almost entirely closed to Mr. Sherren and Dr. Head. From the early days of their research, Dr. Rivers had acted as their guide and counsellor. His interest lay rather in the psycho-physical aspect of the work, and he was impressed with the insecurity of this side of the investigation. Introspection could be made fruitful by the personal experiences of a trained observer only.

Lastly, we were anxious to investigate the functions of deep sensibility. Sherrington [25] had shown that muscular nerves contained a large number of afferent fibres. From the beginning of their research, Head and Sherren [17] had tried to determine the sensibility remaining after complete division of all cutaneous nerves without injury to the muscular branches. But accidental injuries of this kind are excessively rare, and they were compelled to attack the problem by indirect and less satisfactory methods. As soon, therefore, as it was determined to make an experimental division of peripheral nerves, means were taken to ensure that the nature of these deep afferent fibres should come clearly to experimental investigation.

At the time of the experiment, H. was nearly 42 years of age and in perfect health. Since boyhood he had suffered from no illnesses, excepting as the consequence of wounds in the *post-mortem* room. None of these had attacked his left arm or hand, which were entirely free from scars or other deformities.

For two years before these experiments began he had given up smoking entirely. No alcohol was ever taken on the days during which he was under examination, and for some years he had abstained from alcohol except on holidays.

On April 25, 1903, the following operation was performed by Mr. Dean,[1] assisted by Mr. Sherren.

An incision 6½ in. (16·5 cm.) long was made in the outer bicipital fossa extending along the axial line of the left upper extremity; this wound was almost exactly bisected by the fold of the elbow. After turning back the skin, the supinator longus was hooked outwards, and the radial nerve (ramus superficialis nervi radialis) was divided at the point where it arises from the musculo-spiral (N. radialis). A small portion was excised, and the ends united with two fine silk sutures. The external cutaneous nerve (N. cutaneus antibrachii lateralis) was also divided where it perforates the fascia, above the point where its two branches are given off to supply the anterior and posterior aspects of the pre-axial half of the forearm. The nerve was sutured with fine silk, and the wound was closed with silk sutures, without drainage. The limb was put up on a splint with the forearm flexed at the elbow, and the whole hand was left free for testing. The wound healed by first intention.

The following morning (April 26, 1903), the radial half of the back of the hand and dorsal surface of the thumb were found to be insensitive to stimulation with cotton wool, to pricking with a pin, and to all degrees of heat and cold. Around the base of the index and middle fingers was a small area insensitive to stimulation with cotton wool and von Frey's hairs, where a response was obtained to the prick of a pin. No sensation was evoked by any manipulation of the hairs within the affected parts on the back of the hand.

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[1] To Mr. Dean our best thanks are due, not only for the exactitude with which he carried out our wishes, but also for his kindness in receiving Dr. Head into his house for the operation.

The area insensitive to cotton wool extended slightly further towards the ulnar aspect of the back of the hand than that of the cutaneous analgesia. Between the two lay a narrow zone, where a painful cutaneous stimulus produced a more unpleasant sensation than over the normal skin.

The most striking fact, however, was the maintenance of deep sensibility over the whole of the affected parts on the back of the hand. Pressure with the finger, with a pencil, or any blunt object was immediately appreciated. All those stimuli commonly used by the clinician to test the presence of "touch" were appreciated and well localized. Mr. Dean, who was not familiar with our previous observations, said he should have thought that sensation of touch was intact, had he not known the nerves had been divided.

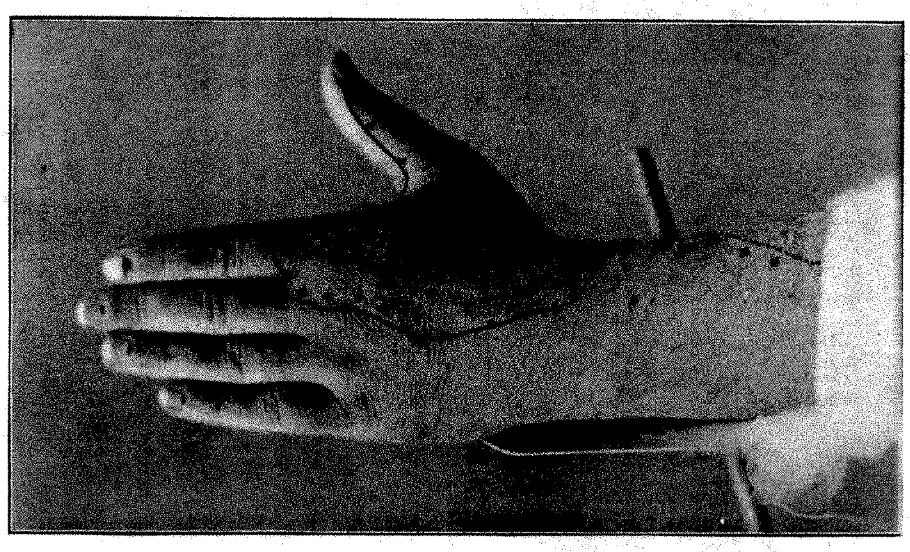

FIG. 1.

To show the extent of the loss of sensation produced by the operation.

The anæsthesia to cotton wool and to von Frey's hairs is bounded by the black line. The analgesia to prick and other cutaneous painful stimuli lay within the red crosses.

The darkness of the affected area is due to its deep red colour compared with the rest of the hand.

On May 4, nine days after the operation, the hand was exposed to a long series of experiments. The most striking features of this examination were:—

(*a*) That very moderate pressure on the abnormal area of the skin was appreciated and could be well localized, whilst touches with cotton wool, or deformations of the skin, produced by drawing the hair outwards, caused absolutely no sensation.

(*b*) In spite of the existence of this sensibility, two compass-points could not be distinguished, even when separated by 8 cm.

(*c*) All sensation was lost to cutaneous painful stimuli, and to heat and cold. In fact, the condition might easily have been mistaken for one of analgesia and thermo-anæsthesia with intact sensibility to touch.

(*d*) Between the extent of the analgesic area and that insensitive to cotton wool, lay a border where the prick of a pin was abnormally painful.

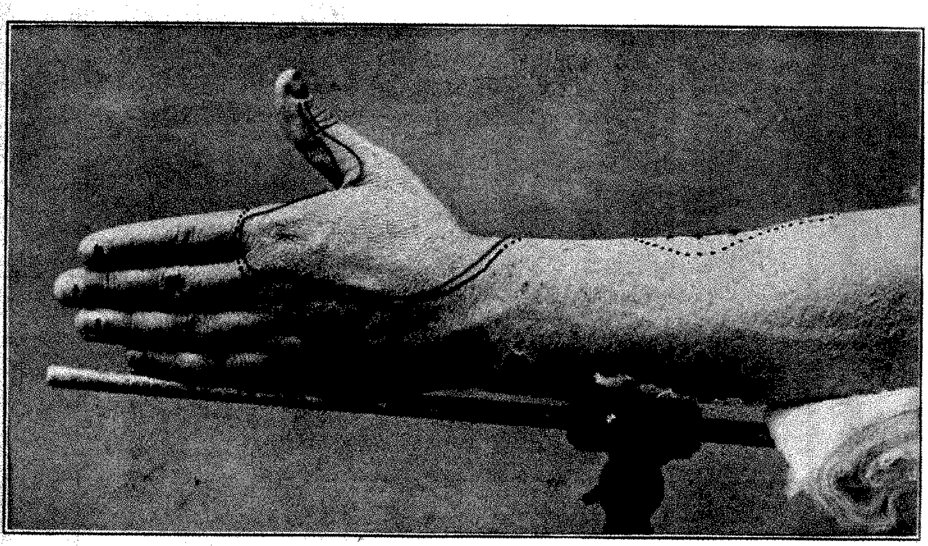

FIG. 2.

To show the extent of the loss of sensation twenty-one days after the operation (May 16, 1903). The black line encloses the loss to cutaneous tactile stimuli; the red line encloses the cutaneous analgesia. Wherever these lines are broken the border was an indefinite one.

(*e*) None of the cold-spots marked out before the operation reacted to the usual stimuli.

By May 4 the skin on the back of the hand had assumed a peculiar condition, which was described on the 7th by Dr. J. H. Sequeira in the following words:—

"The whole of the affected area is of a slightly deeper red than the rest of the skin of the hand. It is dry, and covered with minute hair-like scales. On palpation, the skin appears to be thickened and looks as if it were slightly œdematous; but it does not pit on pressure. A striking feature is the absence of the normal elasticity, which is in remarkable contrast with the rest of the skin. The affected parts do not sweat, while the rest of the hand is permanently slightly moist."

From the time of the operation until the removal of the splint (May 23), the borders of the loss of sensation on the forearm underwent no material change. But H.'s skin has always been peculiarly susceptible to the action of chemical antiseptics, and the necessary cleansing at the time of the operation led to desquamation to within about 3 in. to 4 in. of the wrist. Fortunately, the hand had entirely escaped their action.

On the extensor aspect of the forearm, the loss of all forms of cutaneous sensation was bounded for the greater part by a definite line. Towards the radial aspect, the loss of sensation merged more gradually into parts of normal sensibility. The borders formed a sinuous line, seen on figs. 3 and 4. Over the greater part of the forearm, the loss of sensation to prick was less extensive than that to cotton wool; but nearer to the wrist, the reverse condition seemed to exist.

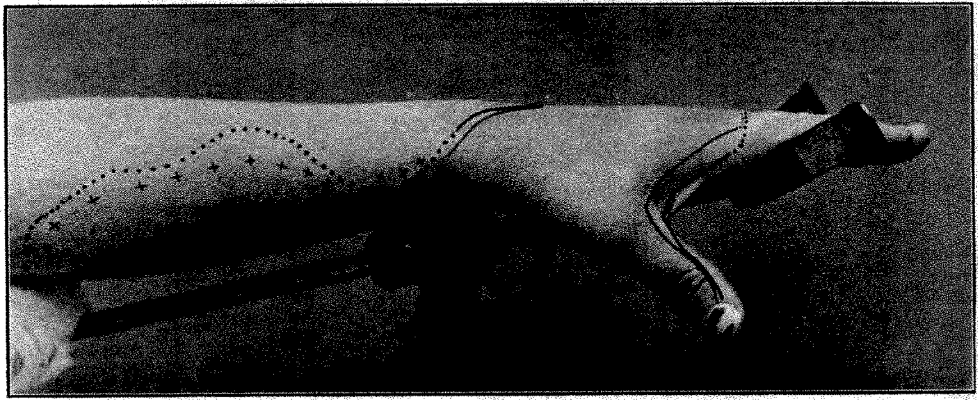

FIG. 3.
Lateral view on the same date (May 16, 1903).

The extent of the cutaneous analgesia on the hand was slightly less than that of the loss of sensation to cotton wool and von Frey's hairs, and to these stimuli all the boundaries were sharply defined, except at the base of the index and middle fingers.

The splint was removed on May 23, and it was then possible to wash the arm vigorously and to remove the loose scales of epithelium. We then discovered that the loss of sensation to prick was everywhere coterminous with, or slightly less extensive than, the loss to cotton wool,

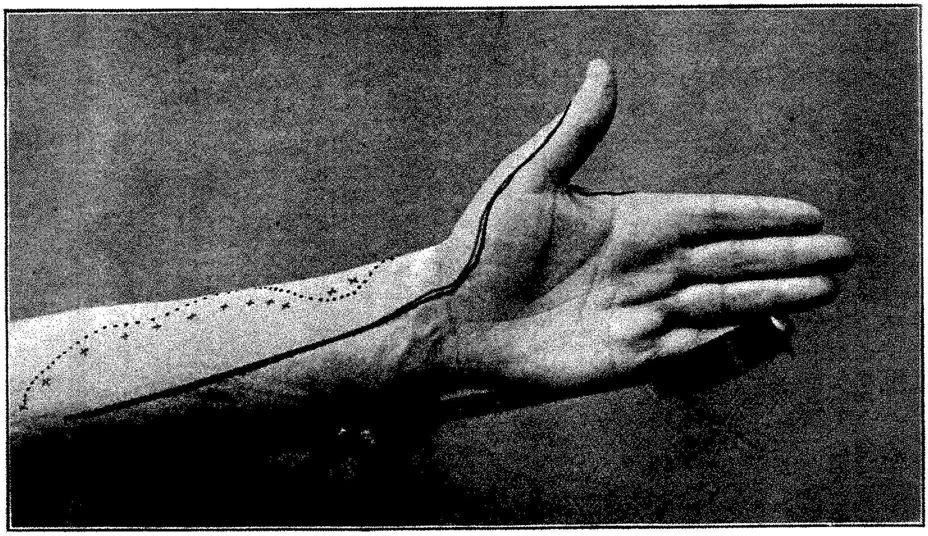

FIG. 4.
Flexor aspect of the forearm on the same date (May 16, 1903).

except near the wrist. Here there was a triangular area, shown on fig. 5, where cotton wool and No. 5 of von Frey's hairs were undoubtedly appreciated, although the skin was insensitive to prick.

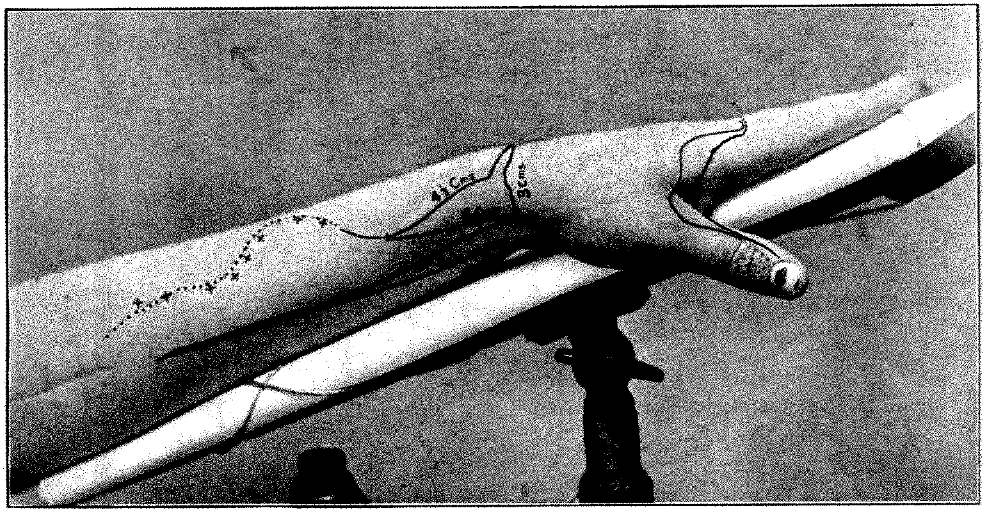

FIG. 5.
To show the loss of sensation on May 26, 1903 (thirty-one days after the operation). On the lateral aspect of the forearm near the wrist is shown the triangular area insensitive to prick and other cutaneous painful stimuli but sensitive to stimulation with cotton wool (*vide* p. 400).

On the back of the hand, sensibility remained exactly in the condition described immediately after the operation. Over the whole area of cutaneous anæsthesia, pressure-touches were appreciated and well localized. Pain could be produced as easily by pressure with the algometer over the back of the affected as over similar parts of the normal hand. Electrical stimuli produced no sensation except when the muscles contracted; then the smallest visible movement was appreciated. To recognize pure movement, produced electrically, without a concomitant cutaneous sensation is a remarkable experience.

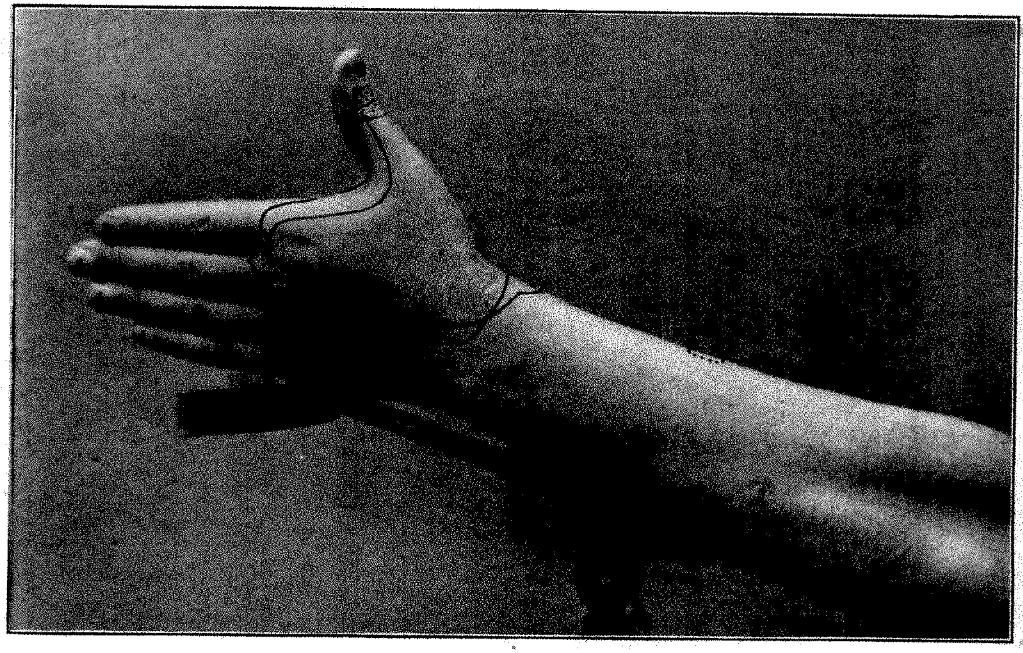

FIG. 6.
To show the loss of sensation on June 14, 1903 (fifty days after the operation).

Though sensitive to the tactile and painful elements of pressure, and to the passive movement of muscles, the back of the hand was anæsthetic to all thermal stimuli; the tissues could be frozen firmly with ethyl chloride without the production of even the slightest sensation.

The first noticeable change in the extent of the loss of sensation was discovered on June 7, forty-three days after the operation. The borders of the area insensitive to cotton wool remained unaltered, but the cutaneous analgesia was distinctly less extensive, and no longer coincided

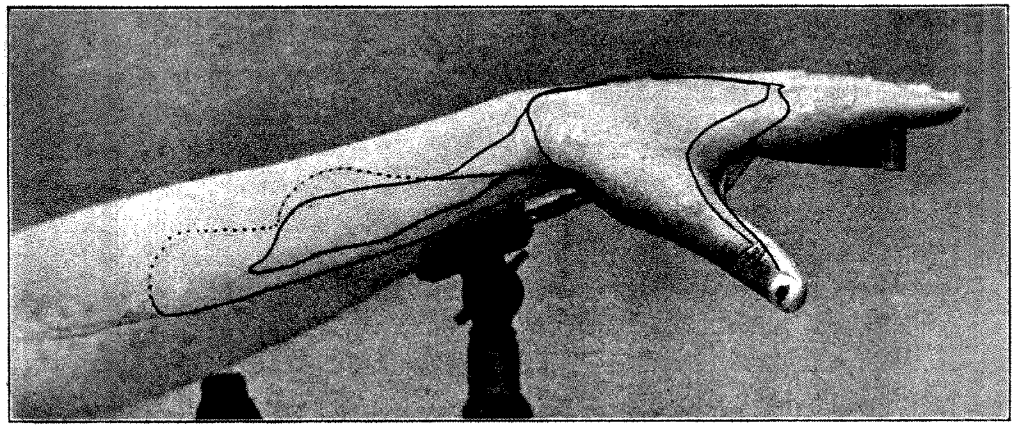

FIG. 7.
Lateral view of the forearm and hand on June 14, 1903.

with it on the flexor aspect of the forearm; the extent of the cutaneous analgesia had diminished for 3 in. (8 cm.), or more, peripheral to the scar. This was particularly noticeable, because the borders of the loss of sensation to cotton wool had remained unchanged.

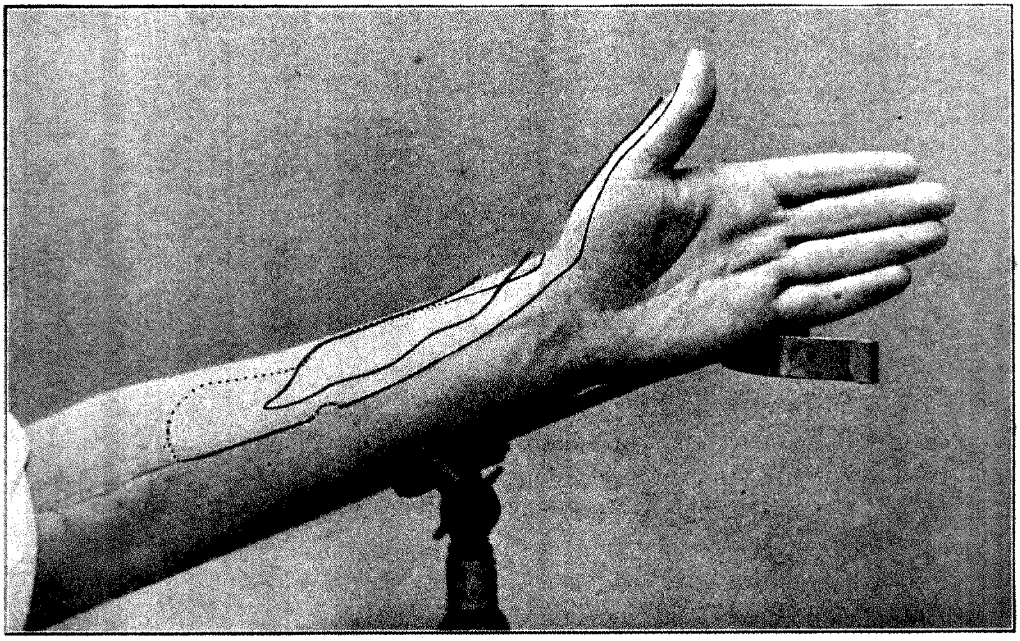

FIG. 8.
Flexor aspect of the forearm on June 14, 1903.

Moreover, the boundaries of the cutaneous analgesia were no longer definite, but were made up of islets, or points, of sensation. Passing from the area of complete loss to parts normally sensitive to a prick, the pin struck spots, where it produced a slowly developed, dull but painful sensation. If, however, this particular spot was not struck, it might be that sensibility was not encountered until another spot was reached, some millimetres nearer the unaffected parts of the limb.

On June 14, fifty days after the operation, the gradual shrinking in extent of the cutaneous analgesia on the arm was found to have continued (figs. 6, 7 and 8), although the borders of the loss of sensation to cotton wool remained entirely unaltered. The loss of sensation to cold corresponded in extent with that of the loss to prick; but, wherever the part was feebly sensitive to the latter stimulus, sensibility to cold seemed to be absent. To all degrees of heat the borders of the loss of sensation had remained unchanged, and the extent of the anæsthesia, even to temperatures between 50° C. and 60° C., uniformly exceeded that of the loss to prick.

By June 20 (fifty-six days after the operation), recovery of sensation had progressed still further. Not only had the extent of the absolute cutaneous analgesia shrunk considerably on the forearm, but the terminal phalanx and a portion of the basal phalanx of the thumb had become sensitive to prick. The extent of the area between the borders of the loss of sensation to cotton wool and to prick in the first interosseous space had increased to nearly 2 cm. (fig. 9). At this date, the markings of the previous week were still visible on the arm, and the boundary of the analgesia lay in many places 0·5 cm. within those determined six days before. And yet, in spite of this rapid improvement in sensibility to prick, the borders of the anæsthesia to cotton wool and von Frey's tactile hairs remained absolutely unchanged.

On the flexor surface of the forearm, there was nothing to show that cold could be appreciated within the border of cutaneous tactile anæsthesia. In the first interosseous space, cold was certainly appreciated well inside the limits of the loss of sensation to cotton wool; the border of the loss to cold lay about midway between that for cotton wool and that for prick.

By July 20 (eighty-six days after the operation), there was no part of the forearm where a prick could not be occasionally appreciated, although in many places this form of sensation was extremely defective. Moreover, considerable changes had occurred in the condition of the hand; the whole of the thumb and the skin over the radial half

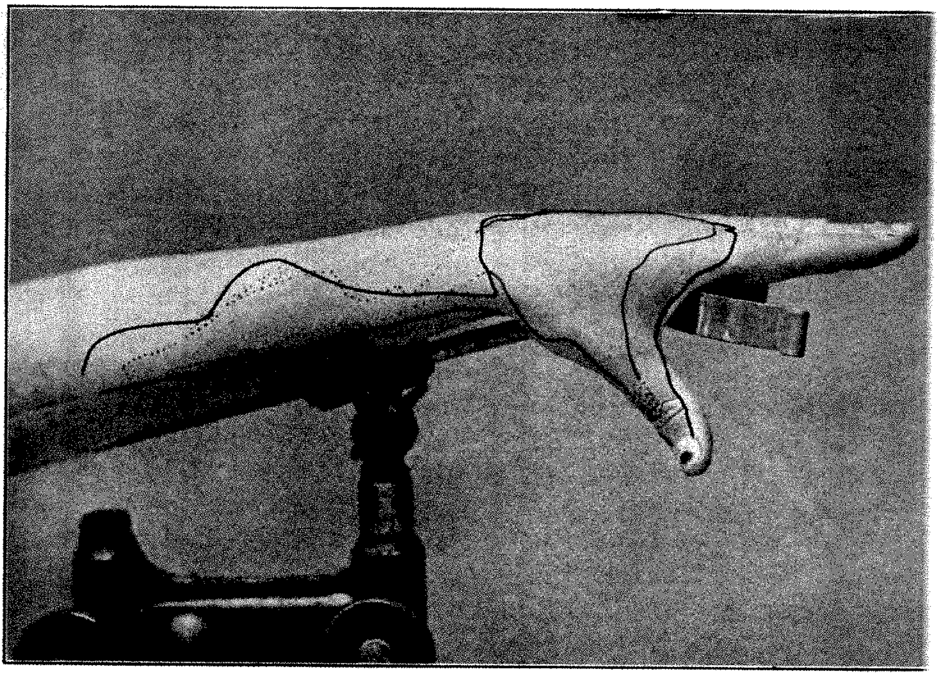

FIG. 9.

To show the loss of sensation on June 20 (fifty-six days after the operation). The cutaneous analgesia on the forearm could not now be defined accurately, but merged everywhere into parts sensitive to prick. It is therefore surrounded by a dotted broken border.

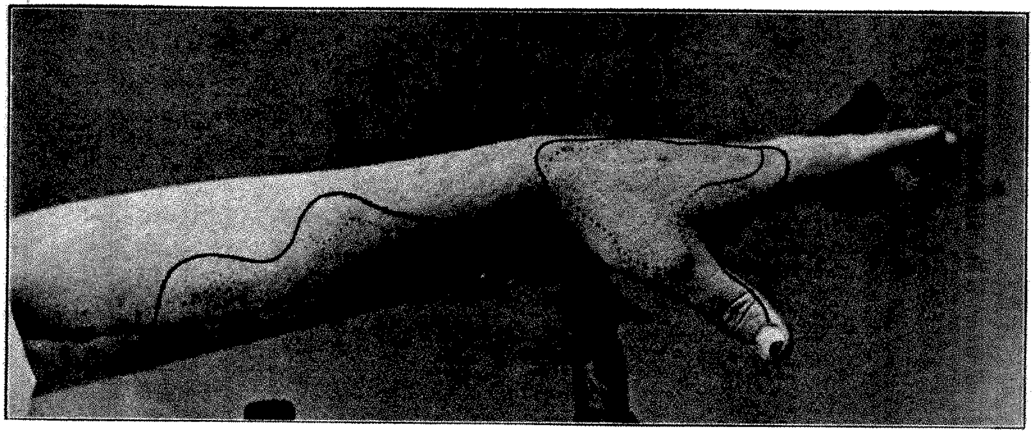

FIG. 10

To show the condition on July 20, 1903 (eighty-six days after the operation). No part of the forearm was entirely insensitive to cutaneous painful stimuli.

of the first metacarpal had become sensitive to prick. The analgesic area on the back of the hand was diminishing from its radial aspect.

In spite of these changes, the borders for the loss of sensation to cotton wool remained exactly as before.

On the forearm, ice was not appreciated with certainty, until the original border of cutaneous analgesia was passed. Water above 50° C. produced pain within the parts now sensitive to a prick, but it was impossible to say whether the pain was accompanied by any thermal quality.

The terminal phalanx of the thumb was certainly sensitive to cold below 17° C. and more doubtfully to heat above 45° C. Within the area of dissociated sensibility in the first interosseous space, and over the ball of the thumb, it was difficult to be sure that any sensation of temperature was produced by ice-cold and hot water; but the border of the thermo-anæsthesia probably lay slightly within that for sensibility to cotton wool.

At this time, some of the hairs on the forearm within the affected area became sensitive to pulling. The sensation produced was slowly developed and excessively unpleasant. It died away, and recurred again, without further stimulation. These hairs lay entirely within the upper anæsthetic patch.

On August 10 (107 days after the operation), the sensibility to prick had further improved, although the extent of the anæsthesia to cotton wool remained entirely unaltered. On August 15, for the first time since the recovery of sensation began, it could be said that parts which were at first insensitive to heat and cold now responded definitely and constantly to these stimuli. Over the upper patch on the forearm, ice uniformly produced a sensation of cold. Temperatures above 50° C. caused a stinging sensation, usually called "burning," but it is doubtful to what extent this contained more than the painful element of heat.

The terminal phalanx of the thumb undoubtedly responded to temperatures above 45° C., and the sensation produced by temperatures above 50° C. contained a thermal element in addition to the stinging pain. Even the proximal phalanx of the thumb had become sensitive to ice, although still anæsthetic to heat.

On August 15 and 16, these observations on the upper patch of the forearm and the terminal phalanx were confirmed, and within these areas we were able to mark out definite cold-spots for the first time since the operation. Four of these lay in the upper patch, and four over the terminal phalanx of the thumb.

By September 9 (137 days after the operation), the whole forearm had become sensitive to cold, and cold-spots were discovered not only in the upper patch on the forearm and in the terminal phalanx of the thumb, but also over the more distal portions of the affected area. The forearm still remained insensitive to heat, except in as far as temperatures above 50° C. produced a peculiar form of painful sensation, usually called "burning."

In spite of the complete absence of any change in the behaviour of the affected parts to cotton wool, sensibility to prick continued to return steadily, and by September 24 (152 days after the operation) a small area only on the back of the hand remained insensitive to this stimulus (fig. 11).

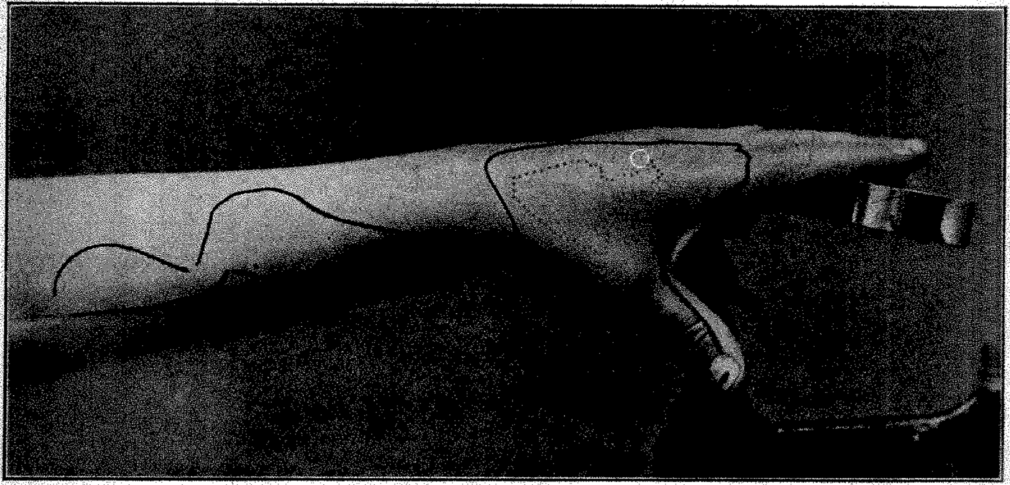

FIG. 11.

To show the condition on September 24, 1903 (152 days after the operation). Over the small irregular area on the back of the hand sensibility to cutaneous painful stimuli was greatly diminished and in places was absent.

The area occupied by the trophic sore is marked with a circle.

Since July 10, when the back of the hand had been too energetically frozen with ethyl chloride, an indolent sore had existed in the centre of the affected area. It tended to heal if protected, but would break down again under the influence of the slight accidents of ordinary life. On September 23, attention was attracted to its condition by the presence of tingling, which had never been noticed before. This led to the discovery that painful sensation, of a dull and ill-defined character, was present in the neighbourhood of the sore. From this time it healed with great rapidity, although no special care was taken to protect it. Once healed, it never broke down again after the return of sensibility to painful cutaneous stimuli.

About this time, part of the first interosseous space, which had become sensitive to prick, began to respond to ice; this return of sensation was found to be associated with a few definite cold-spots. But the affected area still remained insensitive to heat.

On October 3 (161 days after the operation), we noticed, for the first time, that cotton wool produced some sensation over the upper patch on the forearm. This change advanced with considerable rapidity, and on October 6 sensibility to cotton wool was present in a very defective form over both upper and lower forearm patches. The upper of these areas seemed to become sensitive by gradual encroachment from the edges, whilst the lower appeared to recover at the centre as quickly as at the periphery. Later we found that this response was due entirely to the return to the hairs of a peculiar form of sensibility (*vide* p. 385).

About this time (October 8), the upper patch on the forearm became undoubtedly sensitive to temperatures of and above 45° C. An excellent heat-spot was found in the centre of the patch, to which this return was certainly due.

By October 15 (173 days after the operation), no part of the hand was entirely insensitive to prick, although sensation was defective over the parts dotted on fig. 12.

The greater part of the back of the hand now reacted to the more extreme degrees of cold, and the cold-spots had multiplied greatly. By November 1 (190 days after the operation), cold could be appreciated everywhere over the back of the hand, and twenty-four cold-spots were discovered within the affected area. At the same time, one heat-spot was found near the base of the first phalanx of the thumb. This was the only part of the affected area on the hand sensitive to heat.

From this time, the cold-spots and heat-spots rapidly increased in number over the back of the hand, the increase proceeding step by step with the recovery of sensibility to cold and to heat.

With the gradual return of sensibility to pain, cold, and heat, we noticed that the sensation tended to be widely diffused, and was not infrequently localized in some part remote from the point of stimulation (September, 1903). If, for instance, ice was applied to the proximal portion of the forearm, a sensation of coldness was produced in the thumb. The site of this referred sensation remained the same, whatever the nature of the stimulus, provided it was one to which the affected area had become sensitive.

By December 3 (222 days after the operation), the peculiar tingling sensation produced by cotton wool could be evoked by stimulating the thumb and the adjoining interosseous space. This sensibility rapidly increased in extent, until there was scarcely any part of the affected area from which it could not be produced (December 6). The sensation was one which could be expressed only as a general state of diffuse painless tingling. Moreover, it was found that parts which gave this reaction to cotton wool were insensitive to No. 5 of von Frey's hairs and to the painless interrupted current, just as in the early days after the operation. Exactly the same borders could be marked out both on the forearm and hand by dragging a pin lightly from normal to abnormal parts; for as soon as the old border of cutaneous anæsthesia to touch was passed, the sensation became a widely diffused tingling pain.

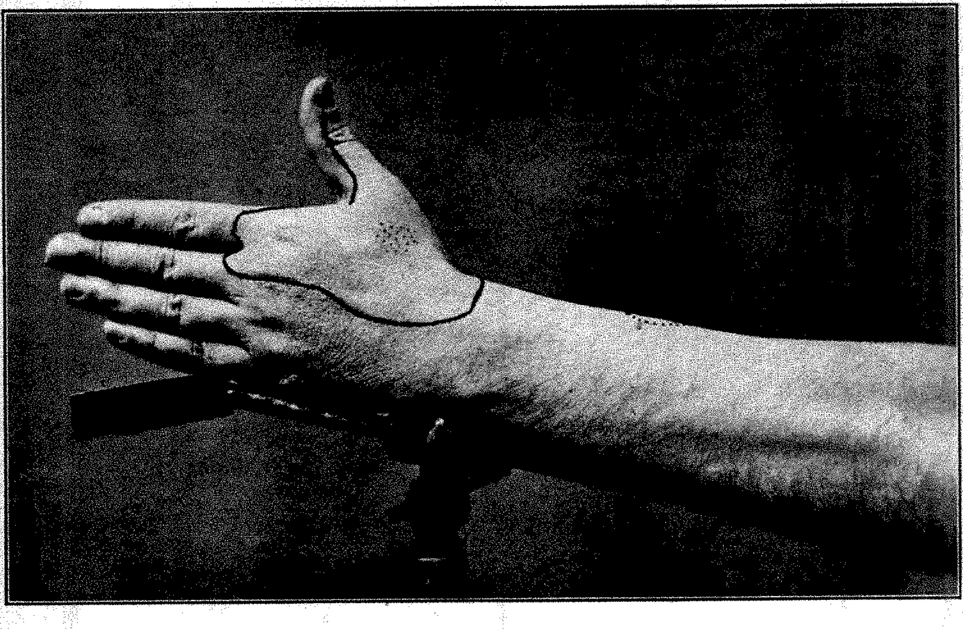

FIG. 12.

To show the condition of the back of the hand on October 15, 1903 (173 days after the operation). The healed sore can be seen as a scar in the neighbourhood of the red dots.

Thus it would seem that the sensibility to cotton wool, which began to return to the forearm 161 days, and to the hand 224 days, after the operation, was not the equivalent of the normal sensation of light touch over hairless parts, but was a peculiar form of hair-sensibility. For the areas endowed with it remained anæsthetic to the painless interrupted current and to No. 5 of von Frey's hairs; moreover, the sensation produced was widely diffused and was referred to remote parts, exactly like the sensation of prick and ice-cold over the same regions. This hypothesis was found at a later date to be correct. For on shaving the areas endowed with this form of sensibility, they became entirely insensitive to cotton wool.

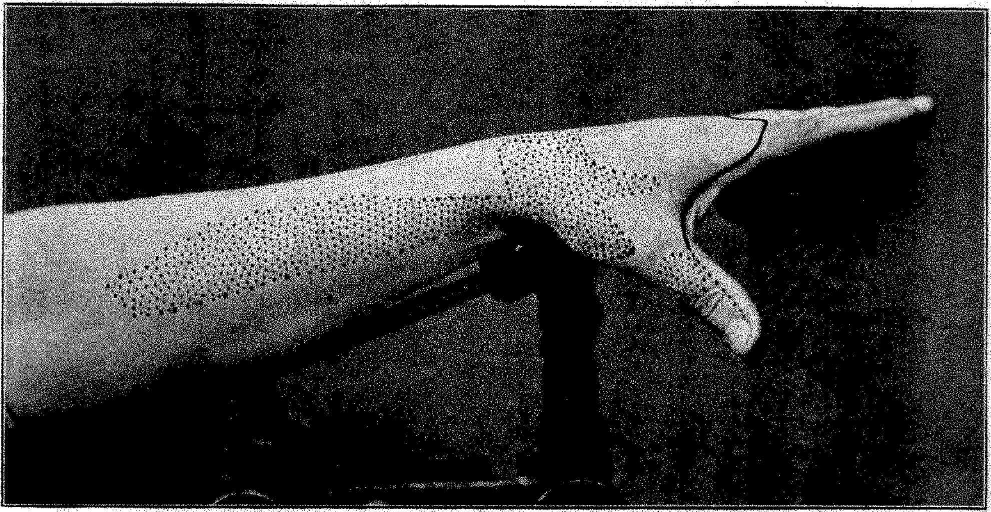

FIG. 13.

November 12, 1904 (567 days after the operation).

To show the manner in which sensibility returned to cutaneous tactile stimuli. The dotted area corresponds to the parts sensitive after shaving to cotton wool and to von Frey's tactile hairs (No. 5). These parts were also sensitive to temperatures of about 36° C.

We could not be certain that the forearm was sensitive to cotton wool when carefully shaved, until April 24, 1904, exactly a year after the operation.

On June 5, 1904 (407 days after the operation), the affected area on the forearm responded to temperatures of 37° C. This sensibility to warmth rapidly increased, and on June 26 was obtained, even with 34° C. Moreover, the sensation produced was one of warmth localized in the part touched. Except that it was not quite so acute, it exactly resembled that produced on the normal skin under similar circumstances. It had none of the diffuse radiation and tendency to reference into remote parts, so characteristic of the sensation evoked by stimulating heat-spots.

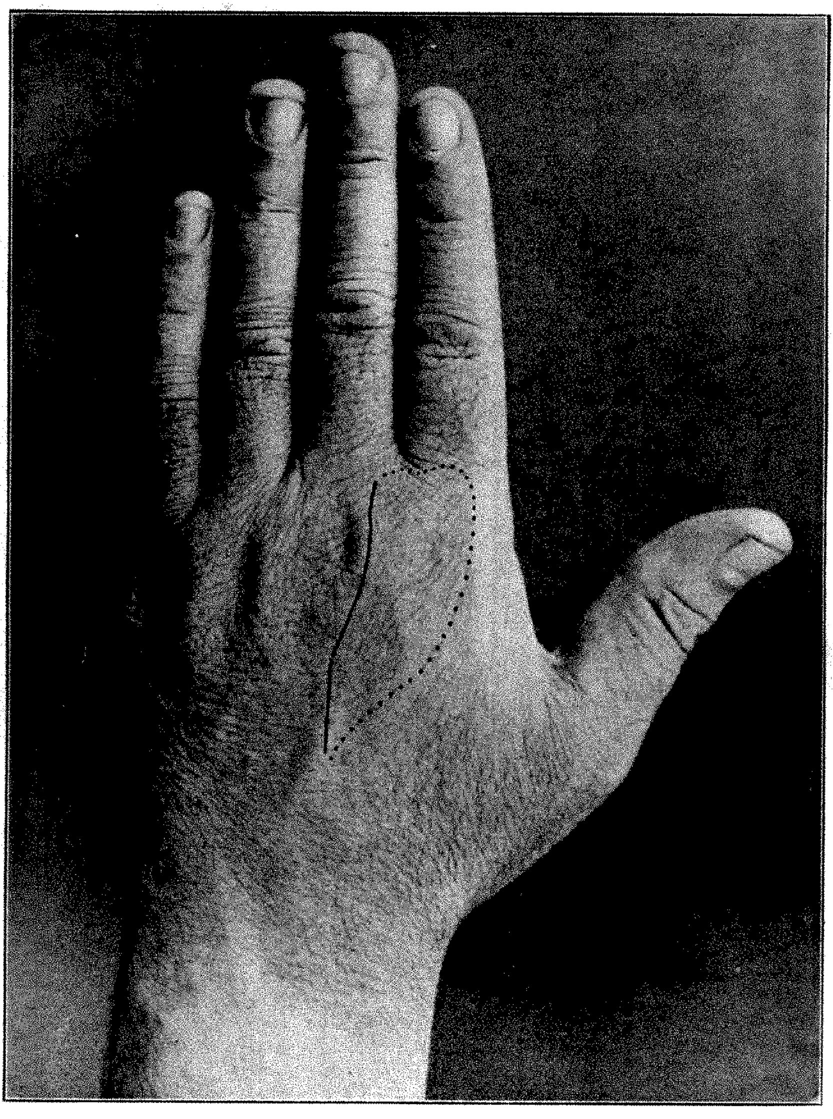

FIG. 14.

To show the extent of the affected area, which is still (1908) supplied with deep and protopathic sensibility only. Its radial border merges gradually into parts that have recovered more completely.

It was not until November 12, 1904 (567 days after the operation), that a portion of the back of the hand (fig. 13) began to be undoubtedly sensitive to warmth (35·5° C.) and to cotton wool after shaving. The diffusion and radiation so characteristic of the previous stage of recovery were at once greatly diminished; so profound was this change that we recognized it before we could be certain of the increased sensibility to thermal and tactile stimuli.

Up till the end of November, 1904, the improvement continued rapidly. But with the advent of winter cold the condition of the hand went back; the referred sensations reappeared, to become as definite as they had been six months before, and the hand became less sensitive to warmth and to cotton wool after shaving.

In March, 1905, it again began to improve. Part of the affected area on the back of the hand became sensitive to No. 5 of von Frey's hairs, and reference greatly diminished. By May 21, a large area on the back of the hand had become sensitive to cotton wool and to minor degrees of heat; stimulation with No. 5 was widely appreciated. A referred sensation could no longer be produced from any part in this condition.

Although this improvement continued throughout the summer of 1905, a small portion of the affected area, lying mainly in the neighbourhood of the knuckles of the index and middle finger, has remained insensitive to No. 5, or to cotton wool after shaving (fig. 14). Even at the present time, this part still is in a purely protopathic condition, sensitive to prick, to ice and to water above 37° C. All these stimuli cause sensations, referred to the dorsal aspect of the thumb and diffused widely around the point to which they are applied. It seems as if one of the branches of the external cutaneous had not reunited, leaving this part of the affected area to be supplied by its fellow and by the radial.

The history of the case may be summed up in the form of the following diary:—

On April 23, 1903, the radial (ramus superficialis nervi radialis) and both branches of the external cutaneus (N. cutaneus antibrachii lateralis) were divided in the neighbourhood of the elbow. Both nerves were reunited with silk sutures and the wound healed by first intention.

This operation did not interfere with sensibility to the tactile and painful aspects of pressure. But the whole of the affected area became insensitive to prick, to heat, and to cold; two points of the compasses, applied simultaneously, could not be appreciated, but localization was preserved.

Forty-three days after the operation (June 7), the extent of the cutaneous analgesia had begun to diminish.

Fifty-six days after the operation (June 20), the analgesia on the forearm had greatly diminished, and the thumb had become sensitive to prick.

Eighty-six days after the operation (July 20), the whole forearm responded to prick, and the back of the hand was becoming rapidly sensitive to this form of stimulation. Cold was not appreciated except over the terminal phalanx of the thumb, and 50° C. gave rise to no sensation of heat.

One hundred and twelve days after the operation (August 15), the proximal part of the affected area over the forearm had become sensitive to cold.

One hundred and thirty-seven days after the operation (September 9), the whole forearm had become sensitive to cold.

One hundred and fifty-two days after the operation (September 24), the whole of the affected area, excepting a small spot on the back of the hand, had become sensitive to prick; the trophic sore healed.

One hundred and sixty-one days after the operation (October 3), cotton wool began to produce a diffuse tingling sensation over the forearm when the hairs were stimulated, but the whole of the affected area still remained insensitive to von Frey's tactile hairs. About the same time, the proximal patch on the forearm began to be sensitive to heat, and a definite heat-spot was discovered in this position.

One hundred and seventy-three days after the operation (October 15), the whole of the back of the hand had become sensitive to prick and, in a less degree, to cold.

One hundred and ninety days after the operation (November 1), the first heat-spot was discovered on the back of the hand.

Two hundred and twenty-five days after the operation (December 6), the hairs on the back of the hand responded with a diffused tingling to cotton wool, but the whole affected area of the forearm and hand still remained insensitive to von Frey's tactile hairs. This sensibility to cotton wool disappeared at once, if the arm was carefully shaved.

Three hundred and sixty-five days after the operation (April 24, 1904), the proximal patch on the forearm began to be sensitive to cotton wool after shaving.

Between *four hundred and seven* and *four hundred and twenty-eight* *days* after the operation (June 5 to June 26, 1904), the affected area on the forearm became sensitive to temperatures between 37° C. and 34° C. The tendency to diffusion and reference greatly diminished.

Five hundred and sixty-seven days after the operation (November 12, 1904), the greater part of the affected area on the back of the hand had become sensitive to cutaneous tactile stimuli, and temperatures below 37° C. evoked sensations of warmth.

CHAPTER II.—METHODS OF EXAMINATION.

It was recognized by experiments before the operation that the ordinary distractions of a busy life were fatal to the detachment required by the sensory tests we wished to apply. We therefore determined that the work should be carried out in St. John's College, Cambridge.[1] The inner of a set of rooms on the top floor of the second court, belonging to Dr. Rivers, was devoted to these observations. Here, absolutely quiet and undisturbed, free from the petty worries of a busy life, H. gave himself over entirely to examination.

As a rule, he travelled to Cambridge on Saturday, after spending several hours in the out-patient department of the London Hospital. But, on Saturday evening, he was found to be in a condition of so great fatigue that no observations could be made until Sunday morning. If, therefore, it was necessary to carry out a long-continued series of tests, H. came to Cambridge on Friday night, returning to London on Monday morning. Occasionally longer periods could be devoted to these observations.

Between April 25, 1903, the date of the operation, and the last sitting with Dr. Rivers on December 13, 1907, 167 days were devoted to this investigation.

The greater part of the work was done in the morning. Then H. went for a walk or a ride, and in the summer occasionally spent the afternoon on the river. The time between 5 p.m. and 7 p.m. was commonly spent in control experiments on normal parts, or in amplifying the results obtained earlier in the day. During the evening, these were talked over whilst H. marked out the hand, and determined the position of the cold- and heat-spots in preparation for further tests next day.

The plan of investigation was debated beforehand, and was frequently committed to paper the night before the testing began. But R. always varied this order to such an extent, that H. remained ignorant of the results until the close of the sitting. This was especially the case with the compass-records; for instance, during many months, H. purposely refrained from inquiring into the nature of R.'s series of observations on the phenomenon of "double ones."

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[1] Dr. Head wishes to take this opportunity of expressing his gratitude to the President and Fellows of St. John's College, Cambridge, for the generous hospitality extended to him during the five years he was their frequent guest.

Throughout the examination, R. recorded exactly the procedure and H.'s answer at the time. At the close of a series, whilst still ignorant of the actual tests applied by R., H. dictated a note commenting on his experiences. Even then he was not told the nature of R.'s manipulations, unless some new fact had appeared which demanded immediate consideration.

Under no circumstances was H. allowed to know at the time whether his answers were right or wrong. For if he was told he had answered wrongly, he was roused to an intense determination to do better, producing thus a mental condition which was found to be unfavourable for the appreciation of sensory stimuli. Knowing his answers had not been correct, he would catch at every accessory circumstance in his attempt to interpret his sensations.

H. always sat with his eyes closed throughout the examination, as he found that this produced in him the condition most favourable for sensory testing. He always answered more correctly to all tests which required no close introspection when he did not attempt to think of what was going on. He would sit with closed eyes, his head resting on the right hand and his attention wandering widely over internal images. He soon learnt to adopt at will this state of passivity, provided he was undisturbed. But a knock at the door, or the entry of the servant, would rouse him into a state in which he again began to interpret his sensations.

H.'s mental processes are based upon visual images to a remarkable degree. Every thought is in some way bound up with internal vision, and even numbers, the days of the week and abstract ideas, such as virtue and cowardice, are associated with images of varying tones of white and black. He cannot recall musical sounds, except by seeing the notes or attaching the sounds to words which are clearly visualized. He has no power of reproducing directly scents or cutaneous sensations. He knows that the scent of violets is pleasing, and recognizes it with ease whenever it is present; but he is unable to recall a scent or a tactile impression in the same way that he can project the memory-picture of an object once seen.

In all these points, he corresponds to the common group of strong visualizers who learn to depend so exclusively on visual images that all other less dominant faculties of sensory reproduction fall into disuse. Throughout this paper we shall frequently allude to the part played in H.'s answers by these vivid mental images.

He was able to reproduce the image of a thing seen with such accuracy that it could be searched for details, at first unnoticed. But this was not the case with any other sensory impression. As soon as the stimulus was removed, he retained so much only as had been noticed at the time; for he was unable to reproduce any sensory images, except those of vision. This peculiarity common to most of those who visualize strongly leads to the following difficulty in testing sensation. Suppose that H. was returning correct answers to stimuli of different kinds applied to the affected area; the one was said to cause a sensation of touch, another appeared hot, and a third seemed to be cold. If, after withdrawing the cold object, R. inquired unexpectedly concerning the nature of the referred sensation, H. was frequently puzzled. Had the question referred to the qualities of a thing seen, H. would have recalled the visual image, examined it carefully and answered accordingly. But as he could not recall any tactile or thermal image of the cold object, he was unable to answer a question relating to some sensory quality to which his attention had not been directed at the time. A prick or other painful stimulus, however intense, evoked a sensation that could not be reproduced.

In the same way when tested with the compasses, H. might answer "two" rightly or wrongly; but if, after the points were withdrawn, he was asked unexpectedly whether they seemed close together or far apart, he was unable to give an opinion. This occurred when the test was applied over both normal and abnormal parts, provided the compasses were suitably adapted.

Again, some unexpected feature in the sensation might arouse H.'s attention, but inability to reproduce the sensory image greatly hindered its introspective study. It was often necessary to repeat the stimulus several times before H. could appreciate each separate aspect of the sensation.

Now, sense-organs, and particularly those of the skin, do not react in an exactly similar way to every repetition of the stimulus. As this is particularly the case with those of the protopathic system, H.'s inability to recapture the features of a somatic sensation in the form of a reproduced image considerably hindered his introspective analysis. For this reason, every record dictated by H. was the direct result of introspection exercised during the period occupied by the stimulus. We have laid stress on this peculiarity, because the majority of persons in this country seem to belong to the group of those who depend on visual images, and approximate, at any rate as far as somatic sensations are concerned, to the condition of H.

Since H. was at the same time collaborator and patient, we took unusual precautions to avoid the possibility of suggestion. No questions were asked until the termination of a series of tests; for we found it was scarcely possible, in the long run, to ask even simple questions without giving a suggestion either for or against the right answer. Sounds and movements, that would have conveyed no information to an ordinary person, would disturb H.'s judgment in a case requiring fine discrimination. The clinking of ice against the glass, the removal of the kettle from the hob, tended to prejudice his answers and destroyed that negative attitude of attention essential for such experiments. R. was therefore particularly careful to make all his preparations beforehand; the iced tubes were filled and jugs of hot and cold water ranged within easy reach of his hand, so that water of the temperature required might be mixed silently.

Towards the end of a series of observations with finer tests over an area of defective sensibility, H. would frequently become uncertain in his answers, because he had forgotten his sensations with the coarser forms of the same stimuli. He might, for instance, speak of contact with the neutral tube as warmth. But occasional unexpected stimulation with a tube at 38° C. would at once correct this tendency, and throughout the further observations the neutral tube would be recognized with certainty. After a long series of "double ones," the application of the compasses widely separated so as to produce a definite sensation of two points frequently produced a similar steadying effect.

At first, we marked out both the affected area of the forearm and back of the hand into squares of approximately 1 cm. But we found the larger area on the forearm unmanageable, especially during the period when sensation changed rapidly. We therefore confined our attention, for the more minute investigations, mainly to a portion of the radial half of the back of the hand 5 cm. in every direction. This was marked out as follows: the hand was laid flat on the table and a line drawn along the axis of the third metacarpal bone. This corresponded almost exactly to the boundary between the normal and affected parts of the back of the hand. As base line, we used a fold of skin over the wrist which was prolonged backwards to meet the longitudinal line at a right angle. From this point, the line along the metacarpal was divided into seven portions, each 1 cm. in length. From the seventh division a line was drawn in the direction of the thumb at right angles to the longitudinal border. This was divided into five portions of 1 cm. in length. By drawing longitudinal lines from each of these points parallel to the axis of the third metacarpal, and by crossing these by five transverse lines parallel to the distal base line, a series of 1 cm. squares, twenty-five in number, could be constructed. On most occasions, we used these squares only as shown on fig. 17, but at times the whole of the back of the hand was marked out into centimetre squares (fig. 21). This was a somewhat tiresome procedure and materially disturbed the sensibility of the affected area. Such marking should never be undertaken shortly before sensory tests are employed. Moreover, it is extremely difficult, even with the greatest care, to ensure the exact correspondence of the squares on different occasions. The skin on the back of the hand is extraordinarily flexible, and any change in the position of the fingers modifies the size and appearance of the squares to a remarkable degree. After the base lines had been settled, we therefore attempted to mark out the squares with the hand exactly in the position adopted in the photographs. Occasionally, these squares were not allowed to become erased for long periods (*e.g.*, from January 28 to March 12, 1906), so that, whatever its faults, we might be certain we were photographing the same field.[1]

On returning to London after each series of sittings, life-sized photographs were taken of the markings on the back of the hand and another set on a smaller scale, including the forearm. Our best thanks are due to Mr. Wilson, Photographer to the London Hospital, for the care and skill with which these records were taken.

Many of the methods used by us in this research have already been described in papers written in conjunction with Mr. Sherren [17] and with Dr. Thompson [18]. We shall therefore confine ourselves to those points, which specially concern the present paper.

Superficial tactile sensibility is usually tested by means of cotton wool stroked gently across the part. Unfortunately, however, such a method suffers from two disadvantages: it frequently fails to act as an effective stimulus over hairless parts, such as the palm of the hand, and any mechanical disturbance of the hairs excites both protopathic and epicritic sensibility. Gentle stroking with cotton wool is not a specific stimulus to hair-clad parts, as far as the peripheral nervous system is concerned. Since the whole of the area affected by our experiment was covered with long hairs, we have always used this test, both before and after shaving. It is no easy task to shave the forearm and back of the hand so cleanly that no stumps project above the surface of the skin. But throughout the protopathic stage, H. soon learnt to recognize by the widespread tingling character of the reaction, that one or more hairs had not been completely shaved. This was invariably confirmed by the use of a magnifying glass of low power, and these hairs were then removed by the direct reapplication of a sharp razor.

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[1] We would suggest that if this experiment is repeated it would be wise to tattoo certain fixed points on the skin before the operation. This would ensure that each square always occupied exactly the same area.

We never tested any part immediately after shaving, on account of the material diminution in sensibility it produced. Usually the part was cold-lathered, shaved and then carefully cleansed in hot water. After an interval of an hour or more, the tests with cotton wool were reapplied. The hand could never be shaved over-night, as by morning the hairs were found to have grown sufficiently to vitiate the experiment.

These precautions were wasteful of time, and the presence of the hairs was often necessary for the series of observations upon which we were engaged; we therefore learnt to depend upon von Frey's method of testing cutaneous tactile sensibility. Before the operation, Professor von Frey presented us with eight graduated hairs set in handles, which we have used constantly in this research. We cannot sufficiently express our gratitude for his liberality and for the kindly interest he has shown throughout this work.

Each of these graduated hairs for testing tactile sensibility will be spoken of by the number in the first column of the following table. As we have used the same hairs on every occasion, the actual pressure exerted by each is alone necessary for comparing our results. For completeness, however, we also give the measured radii of the elliptical section of each hair. Now it is obvious that from these measurements we can arrive at the pressure per unit area, if the force exerted in bending the hair is divided by its total area in mm.^{2}. The result is expressed in grm./mm.^{2}. But von Frey states ([11] pp. 223 to 229) that this is not a correct method of comparing hairs which are used as graduated tactile stimuli. For this purpose he divides the pressure in milligrammes by the radius of a circle of the same area as the elliptical section of the hair. The result expressed in grm./mm. will be found in the last column of the following table:—

Tactile Hairs.

Number by which the hair is known	Pressure in grammes	Measured radii in μ	Total area in mm.^{2}	Radius of a circle of the same area in μ	Pressure per unit area	Tension
1	0·04	30 × 54	0·005	40	8 grm./mm.^{2}	1 grm./mm.
2	0·1	47·5 × 57·5	0·0085	52	12 grm./mm.^{2}	2 grm./mm.
3	0·21	55 × 90	0·015	70	14 grm./mm.^{2}	3 grm./mm.
4	0·23	40 × 80	0·011	58	21 grm./mm.^{2}	4 grm./mm.
5	0·36	60 × 90	0·017	73·5	21 grm /mm ^{2}	5 grm./mm.
8	0·88	100 × 120	0·0377	110	23 grm./mm.^{2}	8 grm./mm.

Towards the end of our research, we received a second set of hairs from Professor von Frey which were useful in measuring the punctate pressure capable of producing cutaneous pain. These so-called "pain-hairs" exercise considerably greater pressure than those used for testing cutaneous tactile sensibility, and are graduated by calculating the pressure per unit area. Thus, we shall speak of the tactile hairs as No. 5, No. 8, &c., whilst the so-called "pain-hairs" will be known by the pressure they exert per unit area.

So-called "Pain-Hairs."

Number by which the hair is known	Pressure in grammes	Measured radii in μ	Total area in mm.^{2}	Radius of a circle of the same area in μ	Pressure per unit area	Tension
35	1·4	100 × 130	0·041	114	35 grm /mm.^{2}	12 grm /mm.
40	1·8	115 × 125	0·045	120	40 grm /mm.^{2}	15 grm./mm.
70	3	115 × 115	0·042	115	70 grm./mm.^{2}	26 grm./mm.
90	3·6	100 × 130	0·041	114	90 grm./mm.^{2}	32 grm./mm.
100	3·5	80 × 140	0·035	110	100 grm./mm.^{2}	32 grm./mm.
110	4·8	105 × 130	0·044	120	110 grm /mm.^{2}	40 grm./mm.
120	4·3	95 × 125	0·037	110	120 grm /mm.^{2}	39 grm./mm.
150	11	125 × 185	0·073	150	150 grm./mm.^{2}	73 grm./mm.
222	10	115 × 125	0·045	120	222 grm /mm.^{2}	83 grm /mm.
266	12	115 × 125	0·045	120	266 grm./mm.^{2}	100 grm./mm.

Throughout the greater part of this research, we have attempted to measure roughly the force applied in pricking the skin by means of an instrument we have called the "algesimeter." It consists essentially of a sharp needle attached by a flexible joint to a rigid rod. This is weighted and slides freely through two supports placed 10 cm. apart projecting horizontally from a vertical brass bar. When the needle is brought into contact with the skin, the full pressure of the weight on the rod would be exerted on its point, were it not for a fine counteracting spring. This spring attached to the rod and to the upper brass support exactly balances the weight, and the needle exerts no pressure. But, if the instrument is pressed on the skin, this spring is no longer completely extended and the weight exerts a pressure in proportion to the amount, to which it is no longer counterbalanced by the coiled spring. This is read off on a scale attached to the bar, that unites the two guiding arms of the instrument.

Six divisions of this scale correspond to the pressure of 1 grm.; but readings below 15 are of little value as the weight hardly comes into action owing to the friction of the rod. Thus the corrected readings are as follows:—

25 scale divisions ... ... = 5 grm.
31 " " ... ... = 6 "
37 " " ... ... = 7 "
43 " " ... ... = 8 "
49 " " ... ... = 9 "

No such apparatus can give anything but approximate readings. For the moment at which pain is produced by the needle depends on the rapidity with which it is applied. If it is placed on the normal skin with the slightest jar, pain is produced at once, before the spring has begun to be affected. Moreover, the sensation of a point merges gradually into the pain of a prick over normal parts. Throughout the stage of recovering sensibility to prick, no pain was produced until considerable pressure was applied, when the characteristic pain made its appearance. Thus, the readings of the algesimeter formed a useful record of the progress of returning protopathic sensibility within the affected area; but we do not recommend it for general use on the normal skin.

All our earlier observations on the pressure necessary to produce deep pain were made by means of Cattell's pressure algometer. More recently we have used the modified form described in the paper by Head and Thompson ([18] p. 546).

The conditions of our experiment enabled us to investigate thermal sensibility with unusual completeness. Not only was the part explored with tubes containing hot and cold water, but we carefully studied the distribution of the heat- and cold-spots, especially on the back of the hand.

In our preliminary investigations before the operation, we found that different parts of the back of the normal hand were not equally sensitive to thermal stimuli. The skin over the knuckles responded badly, and over the long tendons sensibility seems to be less than over the parts between. After the operation, we avoided these situations as much as possible, especially when employing the finer thermal tests.

Many difficulties surround the testing of sensibility to heat and cold, particularly when dealing with intermediate degrees. A glass tube cannot be employed for finer observations, owing to the great difference between the temperature of its external and internal surfaces. We have, therefore, throughout used flat-bottomed silver tubes with a diameter of 1·25 cm. These tubes were filled with broken ice, or with water at the temperature desired, and contained a thermometer. They were never warmed or cooled from without. When used for testing sensibility to heat, several tubes ranged in a wooden stand were filled with water at temperatures considerably higher than those we wished to use for testing; from these, a tube was selected as soon as it had sunk to the temperature required. These silver tubes lose their heat so rapidly that it is possible to use the same one for a short series of tests only.

With such precautions, few difficulties attend the testing of sensibility to the more extreme degrees of heat and cold. But occasionally, when the part is sensitive to painful stimuli but insensitive to heat, a tube at 50° C. and above may be said to be hot, solely on account of the peculiar pain produced. H. soon learnt to differentiate this pain, due to a hot object, from a true sensation of heat; he frequently said, "Any ordinary patient would have called such stimuli hot, because the pain produced is of a kind associated in daily life with the action of hot bodies only. Further, a patient is told to say if he feels heat, cold, or a touch. Given, then, that he knows his thermal sensibility is being tested, he would certainly call the sensation I experience 'hot.'"

Occasionally, contact with a neutral tube would cause an indeterminate and somewhat tingling sensation over the affected area; this was frequently said to be warm, and was one of the greatest difficulties against which we had to contend (*vide* p. 402).

Fewer difficulties surround the testing of sensibility to cold; but it must be remembered that a silver tube always seems colder than one of glass containing water at the same temperature, on account of the greater rapidity with which it abstracts heat. Cold stimuli, more particularly those used for testing cold-spots, are liable to cause a vaso-constriction, shown by a blanching of the skin. This condition is peculiarly unfavourable for all sensory tests.

The cold-spots were sought for with fine copper rods of about 1 mm.

in diameter. These were placed in a glass containing broken ice; on removal, each rod was carefully wiped and, after its flat base had been applied to the skin, was returned again to the ice. We found it best for H. to mark out the cold-spots over night, independently of any previous diagram or photograph. Next morning, they were tested by R., who confirmed or rejected these observations. After the spots had been charted, the result was compared with previous photographs, and if any spots of the first order did not appear, a further examination was made. At the end of the series of sittings, a photograph was taken of the final results (figs. 17 and 18). Occasionally, the back of the hand was protected by a glove, and the marks preserved for several weeks or even months.

For the discovery of heat-spots, we used a simple method which, as far as we can discover, has not been described before. We chose a "soldering iron" consisting of a large copper block fixed to an iron rod let into a wooden handle. This block, about 3 in. (7·5 cm.) in length and 1 in. (2·5 cm.) across every face, we cut down to a pyramidal point. The apex of the pyramid was flat and 1 mm. square. Into the copper block we bored a circular shaft, passing obliquely downwards in the direction of the point. This was of sufficient size to contain the bulb of a thermometer, just under 1 cm. in diameter.

Two of these irons were placed in a jug containing hot water. When sufficiently heated, one of them was removed and dried; the thermometer was placed in the cavity and the instrument laid on a cloth, until the required temperature was recorded. It was then held firmly in the hand like a large pen, and lightly applied, vertically, to the surface of the skin. So large a block of copper retains its heat for a considerable time, and the thermometer gives a sufficient indication of its temperature. This should lie between 50° C. and 40° C., preferably at about 45° C. Higher temperatures cause distinct pain, which complicates the observations; a temperature below 40° C. fails to stimulate most of the heat-spots.

A low external temperature greatly increased the difficulty in discovering both heat- and cold-spots; and in the winter, when the affected hand seemed numb and cold, previous immersion in warm water greatly facilitated their determination.

To test the power of discriminating two points we used a pair of carpenter's compasses, the points of which had been ground down until they gave no sensation of sharpness.[1] For recording our observations, we used the method suggested by McDougall [22]. The compass-points were set at a certain distance from one another; they were then applied to the part to be tested in such a way that sometimes two points, sometimes one point only, touched the skin. The stimuli followed one another in an entirely irregular order, but so that, ultimately, H. had been touched ten times with one point, ten times with two points. Each correct answer was marked with a stroke, whereas a mistake was recorded by a cross. Thus if he answered "one," when touched with two points, a cross was placed below the line; if one point had been called "two," the cross was marked above. By this method it was at once obvious in how many instances he had answered correctly among the ten single and ten double stimuli. The answers whether right or wrong were ranged in strict sequence above and below the horizontal line.

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[1] Most of the instruments, called æsthesiometers, used for this purpose are provided with points so sharp that they are wholly useless. The sharp ivory points of Spearman's instrument should be replaced by blunt ones.

Perfect appreciation of the compass-points at a distance of 4 cm. would be represented thus—

$$4\text{ cm. }\begin{array}{c|l} 1 & \text{III.}\qquad\qquad\text{II.}\qquad\text{IIII.}\qquad\text{I.} \\ \hline 2 & \qquad\quad\text{IIII.}\quad\text{III.}\qquad\quad\text{III.} \end{array}$$

If, however, H. was unable to differentiate the two points, answering "one" to every stimulation, the record would stand—

$$4\text{ cm. }\begin{array}{c|l} 1 & \qquad\quad\text{IIII.}\qquad\qquad\text{II.}\quad\text{IIII.} \\ \hline 2 & \text{XX.}\qquad\quad\text{XXX.}\quad\text{X.}\qquad\quad\text{XXXX.} \end{array}$$

Less complete failure would be represented by some such formula as—

$$4\text{ cm. }\begin{array}{c|l} 1 & \qquad\quad\text{IIXX.}\qquad\qquad\text{XI.}\qquad\text{IXXI.} \\ \hline 2 & \text{XIX.}\qquad\qquad\text{IIXX.}\quad\text{XXI.} \end{array}$$

In the following chapters these records are translated into the number of answers which were right (R.) or wrong (W.) for the sake of simplicity.

Observations made before the operation showed that the threshold for the flexor aspect of the left forearm lay at about 3·5 cm., when the compass-points were applied in the longitudinal axis of the limb.[1] Over the radial half of the back of the hand, under similar conditions, it lay between 1·5 cm. and 2 cm.

Of all sensory tests, the results obtained with the compasses are most influenced by accessory conditions. A stranger entering the room, or anything that disturbed the quiet state of internal absorption, would at once diminish the accuracy of H.'s answers. On one occasion, R.'s servant entered our workroom in the middle of an almost perfect series of answers: they at once became less accurate—

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[1] Throughout this research all compass-tests have been applied in the longitudinal axis of the limb.

$$6 \text{ cm. } \frac{1 \mid 2\text{ R. } 3\text{ W.}}{2 \mid 5\text{ W.}}$$

After his withdrawal H. again began to answer as before—

$$6 \text{ cm. } \frac{1 \mid 9\text{ R. } 1\text{ W.}}{2 \mid 9\text{ R. } 1\text{ W.}}$$

Any profound cooling of the skin, or even the occurrence of a pilomotor reflex, greatly diminishes the accuracy of the answers to compass stimulation. When the coat is removed, and the sleeve is rolled up, "goose-skin" is frequently produced; testing should not be begun until this has entirely passed away.

We always began a series of tests with the compass-points widely separated from one another (9 cm.). Not uncommonly the records considerably improved as the distance was gradually diminished, and were frequently better at 7 cm. than at 9 cm.

This well-known phenomenon seemed, in H.'s case, to be associated with the increasing detachment of his attention from the procedure of testing. The following series of records obtained from the abnormal area on the left forearm are a good instance of such improvement.

$$6 \text{ cm. } \frac{1 \mid 5\text{ R. } 5\text{ W.}}{2 \mid 10\text{ R.}} \qquad 5 \text{ cm. } \frac{1 \mid 5\text{ R. } 5\text{ W}}{2 \mid 6\text{ R. } 4\text{ W.}} \qquad 4 \text{ cm. } \frac{1 \mid 9\text{ R. } 1\text{ W.}}{2 \mid 9\text{ R } 1\text{ W.}}$$

The improvement at 4 cm. was associated with complete wandering of attention from the manipulations. When at the close R. asked whether there was anything to say about these observations, H. could have quite believed that nothing had been done: He was thinking about a book he had been reading and was completely absorbed, until recalled by R.'s question.

Occasionally, especially after exercise in the open air, this condition of detachment would pass into sleep. We noticed that the answers seemed to improve up to the point at which H. ceased to reply and therefore made several observations on the effect of somnolence on the compass-records. On October 26, 1907, H. fell asleep at the close of the following record—

$$4 \text{ cm. } \frac{1 \mid 7\text{ R. } 3\text{ W.}}{2 \mid 7\text{ R. } 3\text{ W.}}$$

an unusually good formula for the affected forearm. He was wakened and after a short interval it was found that the same distance of 4 cm.

was completely below the threshold; every double stimulation was said to be "one." He was allowed again to settle himself in the armchair and R. continued to test him with the points of the compasses at the same distance. With the return of the somnolent state the records improved; the total sixty stimulations gave the formula—

$$4\text{ cm. }\frac{1\mid 21\text{ R. }9\text{ W.}}{2\mid 26\text{ R. }4\text{ W.}}$$

but of these the first and second twenty obtained when H. was more nearly asleep were better than the last series.

First series

$$4\text{ cm. }\frac{1\mid 6\text{ R. }4\text{ W.}}{2\mid 9\text{ R. }1\text{ W.}}$$

Second series

$$\frac{1\mid 7\text{ R. }3\text{ W.}}{2\mid 10\text{ R.}}$$

This sleepy condition which is so favourable for results with compasses is one that requires absolute freedom from all external appeal to responsible action. It is a condition which H. has never succeeded in producing surrounded by the multifarious interruptions of home.

Conversely, concentration on the details of the compass-test greatly diminished the accuracy of H.'s answers. During a large number of examinations, directed towards elucidation of the phenomenon of "double ones," H. was asked to state whether the two sensations seemed to be far apart and, if possible, to indicate the position of the two spots. This required much concentration of attention on the details of testing and considerably raised the threshold.

To measure the power of appreciating roughness, we used Graham Brown's æsthesiometer. This instrument consists of a smooth metal surface from which small cylinders can be made to project for a measurable distance. In the pattern we used, a complete turn of the screw caused each of the six small cylinders to project 0·5 mm As each complete turn was divided into ten equal parts, each of these divisions represented a projection of 0·05 mm.

The smooth surface was passed across the skin, and then the cylinders were made to project until a sense of roughness or "raking" was produced. In every case, the most careful comparative observations were made over similar parts of the sound limb.

For some of our observations on localization, we used the method of Victor Henri [19]. H. was given a life-sized photograph of the back of his hand and was told to mark on it the spot stimulated. But for the majority of our observations, we depended on verbal description of its position or on pointing with the index of the right hand. H.'s strong powers of visualization rapidly led to the development of what may be called a visual map of the affected area. He had but to close his eyes to see a picture of his hand with the affected area marked upon it as clearly as in a photograph. As soon as a spot was stimulated, he saw its position on this map and at once described the neighbouring landmarks. He could even give approximate measurements; for instance, he would say that the point stimulated lay in "the interosseous space about 1 in. from the head of the first metacarpal." Occasionally, he was allowed to point with the index finger of the right hand; but, since this in itself acts as a stimulus, it should be rarely permitted and should be reserved for special occasions.

Unfortunately, the affected area on the back of the hand was too small for the satisfactory determination of the relative shape of different objects applied to the skin. Squares, triangles, and circles of wax or of india-rubber which lay well within its borders could not be distinguished with certainty over similar parts of the normal hand.

Deep sensibility was not disturbed by the operation. The vibrations of a tuning-fork were appreciated from the beginning, and this test played no further part in our investigations.

CHAPTER III.—THE PHENOMENA OF DEEP SENSIBILITY.

That the muscles were endowed with sensory nerves was a necessary corollary to the universal acceptance of a "muscle sense." But Sherrington [25] was the first to demonstrate afferent fibres in the nerves of skeletal muscles. By degenerative methods he traced their course to the muscles, and, in the opposite direction, showed that they entered the spinal cord by the posterior roots of those segments which gave rise to the motor fibres of the same muscles. This discovery did not receive the attention which was due to it, because it seemed to be little more than the last stone necessary to support the universally accepted hypothesis of "muscular sense."

But we long ago suspected that the existence of so many afferent fibres in the muscular nerves was not connected with the power of estimating movement only.

At the beginning of their investigation, Head and Sherren were brought face to face with the problem of "deep sensibility." They found, when all the cutaneous sensory nerves to a part were divided, that it was not of necessity totally anæsthetic. But, although they saw that the only structures which could account for the existence of this sensibility were the afferent fibres in the nerves of the muscles and tendons, accidental lesions of nerve trunks gave little opportunity for bringing this question to a direct issue. Accidental lesions usually divide mixed nerves containing both the fibres to the skin and to the muscles. By chance it may happen that one group has regenerated whilst the other group remains divided (as in Case 28, p. 321, Head and Sherren [17]). But it is impossible to say how far the characters manifested under these conditions by deep sensibility are normal, and how far they are due to incomplete regeneration.

We therefore determined in our experiment on nerve-division to bring this question to a direct issue. A large area of skin was to be robbed of its sensory functions entirely, but the sensibility of the deep parts was to remain undisturbed. By this means, we hoped to have the opportunity of discovering the nature of the sensibility subserved by the afferent fibres of the nerves to the muscles and other deep structures. The result far exceeded our expectation. We found that deep sensibility is an important factor in the sum of afferent impulses which pass into the central nervous system. For the impulses conducted by the afferent fibres of these deep nerves underlie our sensations of tactile and painful presure, of the locality of deep touch, and of the position of the parts in space.

All these sensory qualities are associated with some aspect of pressure, and all are undisturbed by the denervation of the skin. They can therefore be united into one group under the name of "deep sensibility," which will form the subject of the present chapter.

The observations upon which the statements in this chapter are based were made between April 26 and July 20, 1903, when cutaneous sensation began to return to the back of the hand. During this period the sittings occupied twenty-two separate days; so that we had ample opportunity for studying the peculiar behaviour of a part where the skin had been rendered totally insensitive.

(1) *Tactile Pressure.*

As soon as H. regained consciousness after the operation, he was delighted to find that no part of the back of the hand was insensitive to a touch with the finger or similar hard object. The next day he was carefully tested by Mr. Sherren, who found that over the area of cutaneous insensibility on the back of the hand a pressure-touch with the rounded end of a pencil was not only appreciated every time, but was localized to within ½ in. (1·25 cm.) of the spot touched.

Nine days after the operation, Dr. Rivers summed up the results of an extended series of observations in the following words :—

"The most striking features of the examination of May 4 were that slight pressure on the abnormal area of the skin was appreciated and could be localized, whilst touches with cotton wool or deformations of the skin, caused by drawing a hair outwards, produced absolutely no sensation."

Whether a sensation was or was not elicited, when a thick camel's hair brush was applied to the dorsum of the hand, depended largely on the way in which the brush was used. If applied suddenly and vertically to the skin so as to cause a jar, a slight sensation of touch was produced; but when the pressure was made more gradually, no sensation was appreciated until distinct deformation of the brush occurred. Even in this case slight pressure only was necessary to evoke a sensation.

In the same way, stroking the part gently with a wisp of cotton wool was entirely unperceived, in spite of the thick growth of hair on the back of H.'s hand. But cotton wool, balled together into a "swab," such as is used for sponging a wound, caused a sensation if pressed upon the affected area. Slight pressure with such a ball of cotton wool might be perceived when it was put on or taken off only, and it was possible to place it on the skin with so slight a pressure that it was not appreciated at all.

The more gradually contact was established between the stimulating object and the affected part, and the smaller the pressure applied, the less likely was it that a sensation would result. All our observations showed that parts endowed with deep sensibility only are especially sensitive to jarring impact.

Not even stimulation with No. 8 of von Frey's hairs could be recognized, when applied to the affected area on the back of the hand.

When the skin was gently raised between the finger and the thumb so as to form a loose fold, it was found to be entirely insensitive, even to grave pressure.

Similarly, no sensation was experienced when considerable traction was exerted on a hair; the skin could be elevated to the maximum extent until the hair was pulled out, and no sensation was evoked. But a scarcely visible deformation of the skin by pressure was at once appreciated.

On several occasions, when the back of the hand was deeply frozen with ethyl chloride, touches were distinctly appreciated on the frozen area. On one occasion, H. stated that he could recognize no difference between the touches on the frozen portion and those on the surrounding parts. In this observation, not only was any possible sensibility of the skin excluded, but also that of the more superficial layers of the subcutaneous tissues, and it shows that they are endowed with sensibility at a considerable depth.

Several introspective observations were made on the character of the sensations of deep touch. On one occasion, H. recorded that without careful attention, no difference in quality would have been noticed between touches produced by pressure on the anæsthetic and normal areas. Pressure with the head of a pin on the normal skin produced a tactile sensation, together with sensations of slight cold and of hair-stimulation. On the affected area, the latter elements were no longer present, but the fundamental quality of the sensation seemed to remain the same, so that when the head of the pin was passed across the border separating the normal and affected areas, a considerable effort of attention was necessary to detect when the change occurred. The differences in quality were of such a kind that it is very improbable they would be noticed by any but a trained observer. On a later occasion, observations were made by stimulating the normal right hand covered with a thin rubber glove, when H. noted that the quality of the touches resembled that experienced from the abnormal area.

The most extended observations were made on the back of the affected hand, because of the rapidity with which sensation began to return to the skin of the forearm. But during the short time at our disposal, the anæsthetic parts of the forearm were found to behave exactly in the same way as the insensitive area on the dorsum of the hand.

In conclusion, there is no doubt that the back of the hand was so sensitive to contact, that most observers would have said the sensation of touch was unaffected.

(2) *Roughness.*

One of the most striking features of a part endowed with deep sensibility is the ease with which roughness can be appreciated.

The utility of Graham Brown's æsthesiometer depends on our power of appreciating roughness, when small cylinders are made to project for a measurable distance from a smooth metal surface. When these projections can be perceived, the sensation is one as if the part was "raked." It was found that, in this respect, the affected parts of the left hand were in no way inferior to similar parts of the right hand.

Thus on June 7 the following readings were obtained :—

	R. (sound).	L. (affected)
0·025 mm.	Not appreciated	Not appreciated.
0·033 mm.	Slightly rough	More definitely rough.
0·041 mm.	Definitely rough	Definitely rough

There was no gross difference between the two sides, but, if anything, the superiority was on the side of the affected hand. On this occasion, H. dictated the following note: "When the instrument was moved across the first interosseous space, I was more certain on the left hand than on the right that it was smooth or rough. On the sound hand I was more frequently confused by the sensations which arose from the necessary contact with hairs; no such confusing accessory sensations arose on the abnormal hand. The sensation of raking was much purer on the affected side."

If the anæsthetic skin was gently lifted into a large fold, this roughness ceased to be appreciated until the projections were extended to 0·65 mm. or 0·75 mm. Even then, the "raking" was rarely appreciated, and it was doubtful whether this sensation was not due to traction communicated to deeper structures.

Thus, the power of appreciating roughness is evidently a function of deep sensibility. Complete anæsthesia of the skin, far from diminishing this sensation, seems to make its recognition slightly more easy by removing the possibility of other disturbing sensations.

(3) *Painful Pressure.*

Although the skin of the affected area was totally analgesic to prick and to the painful interrupted current, excessive pressure produced a characteristic aching pain over the back of the hand from the beginning of the experiment.

The first measurements with the pressure algometer were made on June 7, and resulted as follows:—

	R.	L.
First series	4	1·5
	4·5	2·0
	4	2·0
Second series	3·5	3·5
	3·5	2·0
	4·0	2·5

Another series gave the following results, when pressure was applied in the first interosseous space:—

R.	L.
3·25	2·0
2·5	2·5
3·25	1·75
3·25	2·0

These observations showed so consistent a tendency for lower readings to appear on the affected than on the sound hand that pressure was increased, until H. said the pain was severe. This point was reached on the left (affected) side at 3·5, at 5 on the right (sound) hand.

There were local differences on both sides in the amount of pressure necessary to cause pain, but in every case the readings were less over the affected area than over similar parts of the sound hand.

Comparative readings were taken over the second metacarpal bone and over the interosseous space, with the following result:—

	R.		L.	
Over the metacarpal bone	4	3	2	2
Over the muscle of the interosseous space	3	4·25	3·5	3·25

H. thought that the difference between the two hands lay not so much in the quality of the sensation as in the way it developed. On the affected side, pain emerged rather quickly as a definite aching from a dull sensation of deep pressure. On the sound side, the development was more gradual out of a mixed general sensibility. Desire to withdraw the hand was more urgent on the affected side. Moreover, H. said, "I feel more frightened at the application of pressure on the affected side."

When the algometer was pressed on a raised fold of skin against counter pressure of R.'s fingers, no pain was produced with pressures of 8·5. On the normal side, pain was produced with a pressure of 2·25.

Thus, in conclusion we can say that it is one of the properties of deep sensibility to answer to the stimulus of excessive pressure by the production of pain. This pressure-pain is apparently wholly due to the activity of those nervous structures which are not interfered with by complete denervation of the skin.

(4) *Localization.*

The most surprising quality of this deep sensibility is the ease with which tactile pressure is localized. Three methods were employed for testing the power of localization. First, H. kept his eyes closed, but tried to point to the spot touched with his right hand; or he was allowed to open his eyes and point, without contact with the skin, to the place he supposed had been touched. Lastly, R. touched the affected area at a spot he had marked on a life-sized photograph of the left hand, whilst H. attempted to mark the spot on a similar photograph. This is the method of Victor Henri [19], and in this case it gave surprisingly good results.

A fortnight after the operation, on May 9, it was found that of twenty-nine touches within the affected area, seventeen were quickly appreciated and accurately localized, six were not localized correctly, and six were not appreciated at all. It must be remembered, that at this stage the skin over the affected area was swollen, which somewhat hindered these experiments. The passing away of the swelling rendered the later experiments even more striking.

On May 17 a series of twenty-four observations was recorded by Henri's method on life-sized photographs. The results were remarkable, and it could not be said that there was any difference between the two hands in the quickness and accuracy with which pressure, touches were localized.

R. chose nine spots in various parts of the affected area unknown to H.; these are marked in black on the annexed figures (figs. 15 and 16). The following table gives the places stimulated in order and the position of the spots marked by H. on his photograph:—

(2) Localized exactly.

(3) Localized 1·3 cm. from the spot touched.

(4) Localized exactly.

(8) Lay over the interphalangeal joint of the thumb, and was localized near the metacarpo-phalangeal joint at a distance of 2·5 cm.

(1) Localized exactly.

(9) Over metacarpal of thumb—localized at a spot 2·5 cm. distant in interosseous space.

(6) Localized 0·5 cm. from spot touched.

(5) Localized 0·75 cm. from the spot touched.

(7) Localized 1·0 cm. on the proximal side of the point touched.

(2) Localized exactly.

(4) Localized exactly, so much so that the mark of the previous record was identical with that of this stimulation.

(7) Localized 1·0 cm. from point touched over the same spot as before.

(6) Localized exactly.

(8) Localized exactly.

(9) Localized 3 cm. distal to the spot stimulated.

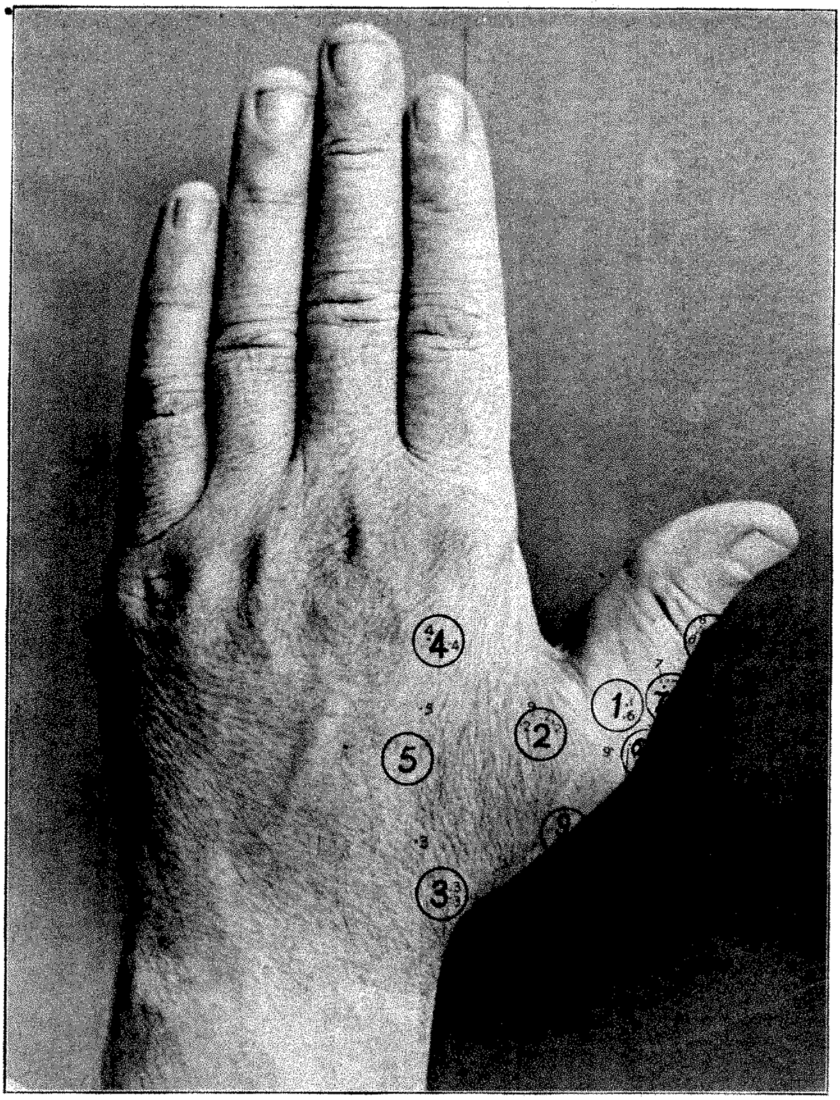

Fig. 15

Reduced to two-thirds the natural size (May 17, 1903).

Certain spots were marked on a life-sized photograph of H.'s hand. These are shown by black numbers within a circle of 1 cm. in diameter.

H. was given a similar photograph and marked upon it in each case the spot he thought R. had touched.

The photograph showing the spots stimulated and that showing H.'s localization have been combined; the marks made by H. are printed in red. Thus, for instance, a red 3 shows the spot marked by H. as the locality of a stimulus applied by R. to the area marked with a black 3.

The order of stimulation is given in the text.

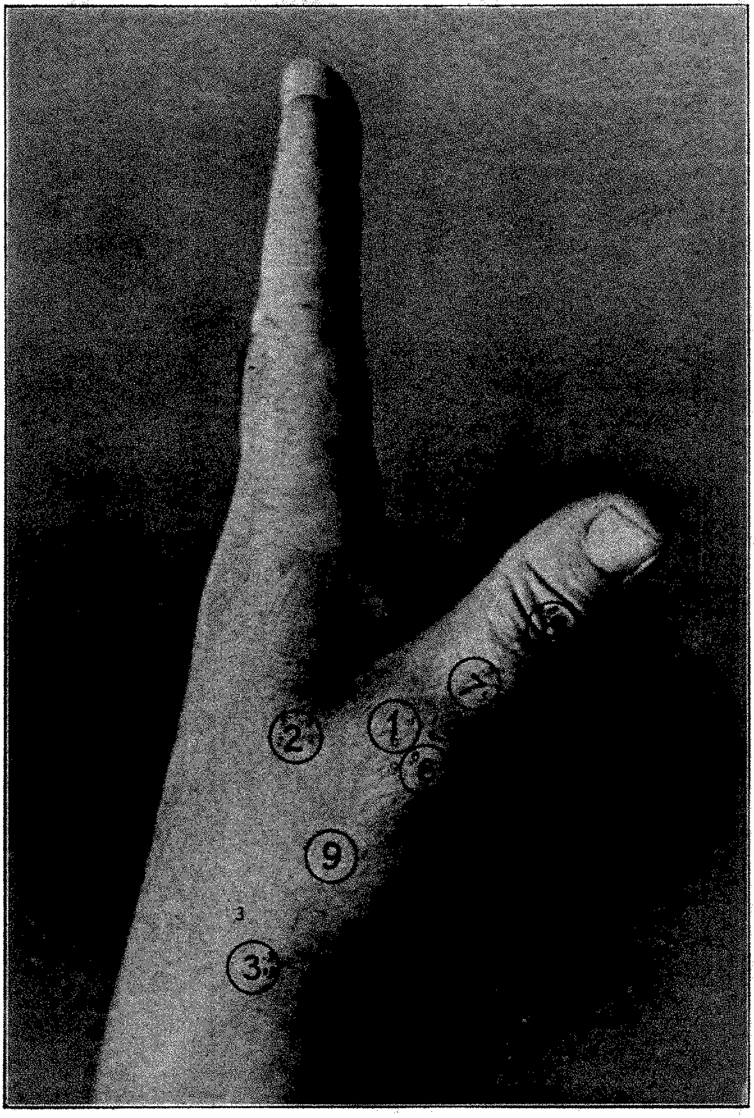

FIG. 16.

In order to test the localization over the spots 8, 7, 6, 9 and 3 two photographs of the lateral aspect of the hand were used exactly as described under fig. 15. These have been combined in the same way and the marks made by H. have been printed in red.

(7) Localized exactly.
(3) Localized exactly.
(6) Localized exactly.
(7) Localized exactly.
(9) Localized 2 cm. distal to the point stimulated.
(3) Localized exactly.
(8) Localized exactly.
(2) Localized exactly.
(6) Localized exactly.

Point 2 was touched three times and in every case was localized exactly.

Point 3 was localized twice exactly and once 1·3 cm. from the spot touched.

Point 4 was localized twice exactly.

Point 6 was twice localized exactly and twice within 0·75 cm. of the spot touched.

Point 7 was twice localized exactly and twice 1·0 cm. from spot touched. The two erroneous localizations fell over the same point.

Point 8 was twice localized exactly. Once it was localized over the proximal joint at a distance of 2·5 cm.

Point 9 showed the worst localization of any of the spots chosen, and was always localized distal to the point of stimulation; twice 3 cm., and once 2 cm.

Thus, all our experiments showed that the localization of a touch sufficiently heavy to cause a sensation was remarkably accurate. This power of localization remained after freezing with ethyl chloride, though, owing to the haste with which such observations had to be made, it was somewhat less accurate than at other times.

(5) *Spacial Discrimination* (*Compasses*).

In spite of the remarkable power of localization, H. was entirely unable to discriminate one from two points of the compasses, even when separated for the widest distance permitted by the size of the affected area on the hand, 6 cm. in a direction longitudinal to the axis of the limb. And yet, over a similar part of the normal hand, a perfect record was obtained at 2 cm.[1]

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[1] Occasionally, when the compasses were applied over the anæsthetic skin of the forearm with the points at distances exceeding 10 cm., H. recognized them as two. But he was clear that this depended on the localization of one point at one place and the other in widely distant part of the limb. He had no sense of inevitable "twoness," as when the two points were separated to a distance above the threshold on the normal skin. The process was one of judgment, in that he knew he was being touched near the wrist and also somewhere up the forearm.

But, as soon as the second point was placed upon the skin a fraction of a second later than the first, H. at once recognized that he was being touched in two places.

When the compasses were 3 cm. apart, he called every simultaneous contact "one," whilst four out of five stimulations with two points successively were recognized and the fifth was said to be doubtful :—

3 cm.	One point				1		1			1		1			1	
	Two points simultaneously		1	1					1		1			1		
	Two points successively	2				2		2					D			2

Even at a distance of 1·5 cm. H. was surprisingly often right in his answers provided stimulation was successive :—

1·5 cm.	One point		1		1								1					
	Two points simultaneously						1		1			1			1		1	
	Two points successively	1		2		2		2		2	2			D		2		D

On the sound side the formula was as follows :—

1·5 cm.	One point				1					1		1		1	
	Two points simultaneously	1		2		2		2					2		
	Two points successively		2				2		2		2				2

And in every case where a right answer was given, H. recognized whether the two points were applied simultaneously or successively.

Thus it is evident that the presence of deep sensibility alone does not make it possible to discriminate two points applied simultaneously.

(6) *Appreciation of Size and Shape.*

All appreciation of size was lost over the affected area endowed with deep sensibility only. Even the flat and the edge of a knife could not be distinguished from one another. H. seemed to have no power of telling the relative size of a series of wax figures, although he at once recognized the relative pressure with which they were applied.

A small square of 1 cm. was placed on the skin with considerable pressure and compared with another figure 4 cm. in diameter applied with little pressure. H. made no statement with regard to the relative size of the objects, but said the first gave a sense of greater pressure. This was repeated many times on different occasions with the same result.

All power of telling the head from the point of a pin was entirely absent over the affected parts.

Unfortunately, the size of the area on the hand did not permit of the complete application of tests for shape. It was found that even a circle, a square or a triangle, cut out of wax so that all lay entirely within a 4 cm. square, could not be distinguished with certainty on the dorsal surface of the sound hand. But, although the answers were wrong as regards the shape, H. had a definite sensation of pressure on a circumscribed surface, a surface with borders and angles. On the affected hand, the sensation was one of pure pressure accompanied by no idea that the object by which the pressure was produced had any shape. Thus, on June 22, it was noted that on the back of the left hand there was a complete absence of any element of shape in the sensations. Pressure was experienced, and this was well localized, but there was nothing to indicate that the body producing the pressure had any shape. But on the sound side there was a distinct impression of form, chiefly of angles here and there, though the total shape could not be perceived correctly.

When a very large surface was applied, H. thought it seemed to him large, because he had a visual picture of his hand on which he had certain points of reference, such as the first and second metacarpal bones with their tendons. He imagined the object was large, because he perceived a sensation from both these widely separated places. But this failed entirely if both spots could be touched strictly simultaneously when the large object was applied to the skin.

(7) *Perception of Movement on the Skin.*

In some of the observations in which the skin was stimulated successively with compass-points, the sensation produced was not so much one of "twoness" as of rocking or pushing on the skin. This led us to test whether the affected area was especially sensitive both to progressive movement over the skin and to rotatory movement of a round object in which the stimulated area of the skin remained the same.

Slight movements were readily appreciated on the affected side, but we could not detect any definite difference in sensitiveness between the two hands.

(8) *Recognition of Muscular Movement.*

Head and Sherren ([17] p. 214) were able to show that perfect recognition of passive movement of the joints was possible when the nerves to deep parts alone were intact. In the case of H. we had no means of attacking the problem, for no part of any finger was totally insensitive to cutaneous stimulation.

But we were able to show that the interrupted current could produce sensation by contracting the muscles only. Even the slightest contraction of the abductor indicis or the adductor pollicis produced a distinct sensation of movement, localized in the muscle. No pain was evoked, unless the muscle was thrown into cramp.

(9) *Temperature.*

The existence of deep sensibility conveys no capacity for appreciating stimulation with any degree of temperature. Ice and water at 60° C. were equally incapable of evoking a response over the affected area of the hand. The parts could be frozen stiffly with ethyl chloride, and H. remained unconscious of any stimulation, provided the normal skin was carefully protected with a thick layer of impervious material.

This freezing produced a numb aching, in no way allied to a thermal sensation, but resembling the "numbness" produced by extended exposure of the hands to severe external cold.

In conclusion, we have shown that the peculiar aptitude possessed by a part innervated solely by the afferent fibres of a muscular nerve is the appreciation of all stimuli which produce deformation of structure. Pressure or jarring contact are quickly appreciated and localized with remarkable accuracy. "Roughness" is as well recognized on the affected as on the sound hand.

Two points can be discriminated if applied successively, but not when contact is made strictly simultaneously.

Although pressure is well localized, all sense of relative size is lost over the affected parts.

Excess of pressure produces an aching pain; and the cramp, caused by repeated electrical stimulation of the muscles, is at once appreciated.

Pressure, which ordinarily causes a sensation of touch or of pain, produces no effect upon consciousness when applied to a fold of skin elevated into a ridge, thus proving that the sensations which are present are not due to any end-organs remaining in the skin.

The presence of deep sensibility conveys no power of appreciating any temperature stimulus.

CHAPTER IV.—PROTOPATHIC SENSIBILITY.

Section 1.—*Borders of Dissociated Sensibility.*

The nature of our experiment laid bare the peculiar qualities of deep sensibility in an unequivocal manner; for all sensory impulses were destroyed, except those passing by way of the afferent fibres of nerves of muscles and tendons. Deep sensibility, as we have described it, is the expression of one set of afferent impulses, uncomplicated by the simultaneous activity of those arising in the skin. It cannot be the result of any abnormal reaction on the part of the central nervous system, nor can it bear any relation to the processes of regeneration.

But when we attempt to analyse the complex of afferent impulses, which travel by way of the cutaneous nerves, we are hampered by the following difficulty: It is not possible to arrange the experiment in such a manner that a large area of skin shall be rendered insensitive to certain stimuli, without at the same time gravely impairing its sensibility to those we desire to study. It is impossible to produce a condition analogous to that of total cutaneous anæsthesia with complete integrity of deep sensibility. We can, it is true, find parts that are sensitive to one group of cutaneous stimuli and insensitive to another; but even these are areas of lowered sensibility.

In our case, we had even less opportunity than usual for studying the primary dissociation of cutaneous sensibility. For, on the anterior surface of the forearm, the loss of sensation to prick and to cotton wool corresponded exactly. Towards the radial aspect its boundaries were ill-defined to both stimuli, merging gradually into parts of normal sensibility. But over the back of the hand lay a narrow border, 2 mm. in breadth, insensitive to cotton wool but sensitive to prick. Within this area, so vivid was the response that the skin might have been considered over-sensitive to painful stimuli. Within ten days of the operation, R. noted that the border on the back of the hand was "hyperalgesic." H., describing his sensations, said that within this area the prick of a pin was intensely disagreeable, far in excess of anything experienced on normal parts; he could not refrain from crying out and withdrawing his hand. When the hairs were pulled, no response was obtained from any part of the analgesic area. But, as soon as that portion was reached where the skin was sensitive to prick but not to light touch, H. at once exclaimed that the sensation was "stinging"; he was unaware of the nature of the stimulus, but experienced a diffuse unusually disagreeable sensation only. If the induction coil was so arranged that it produced a current, scarcely, if at all, painful over the normal skin, it caused a more disagreeable sensation over the area of dissociated sensibility.

When the normal skin was pricked, H. at once said, "That was a prick," but did not cry out or withdraw his hand. But a prick or any other painful stimulus applied within the area of dissociated sensibility produced an immediate withdrawal of the hand and an exclamation of pain. Yet, in spite of this vigorous expression of discomfort, he was able to recognize that the dissociated border was less sensitive even to cutaneous painful stimuli than the normal skin. A stronger stimulus was required to produce pain, but when once evoked the sensation was more disagreeable than over normal parts.

Within three weeks of the operation, another small dissociated zone appeared in the first interosseous space around the distal border of the affected area. Here sensibility to painful cutaneous stimuli was so low that they were followed by no increased reaction. A prick produced a slowly developed, dull aching, different from the exaggerated discomfort evoked on stimulating the border on the back of the hand. Moreover, this small area in the interosseous space was insensitive to all thermal stimuli, and neither cold- nor heat-spots could be discovered within it. It was evidently so little sensitive to protopathic stimuli that the skin could respond to painful stimulation only, and even this response was extremely feeble.

Section 2.—*Pain.*

The back of the hand became sensitive to painful cutaneous stimuli within eighty-six days of the operation. With the steady increase of this form of sensibility, the response to the prick of a pin began to assume the characters of diffuseness and increased unpleasantness, with which the sensations from the dissociated border on the back of the hand had already familiarized us.

At first the sensibility was low and the innervation evidently defective. But in time the whole of the back of the hand responded vividly to cutaneous painful stimuli, though still anæsthetic to von Frey's hairs and other forms of light touch. Within this area the prick of a pin produced an intensely unpleasant sensation of pain. When the point was dragged across the hand from normal to abnormal parts, the sensation became more unpleasant immediately the boundary of the affected area was passed. The change was so sudden and the new sensation so disagreeable that the border could be marked out to within 2 mm.

But although the response was greater, H. early recognized that sensibility to prick was still defective. Tested with the algesimeter, it was found that pain was not produced until the instrument registered from 30 to 40, whilst on similar parts of the normal hand the point was painful at about 25. Thus, although the sensation produced over this protopathic area was much more unpleasant than over normal parts, the sensibility, as measured by the pressure exerted on the point, was distinctly diminished.

Most clinical observations on parts in a protopathic condition must of necessity be made before this form of sensibility has been completely restored. For in most cases epicritic sensibility begins to return whilst the measured pain-threshold is considerably higher than that over similar parts of the normal limb.

Fortunately, a portion of the affected area on the back of the hand still remains insensitive to all epicritic stimuli at the end of five years. Here protopathic sensibility has reached a high grade, and pain is produced as readily by the algesimeter as over normal parts. But, although the stimuli are identical, the sensation over the protopathic area is much more unpleasant. It would be certainly described as "more painful" by any ordinary patient.

The threshold for painful sensation measured by means of the "pain-hairs" is the same over this protopathic area as over an analogous part of the sound hand. No. 120 was painless, but No. 150 caused distinct pain over many places on both hands; with No. 200, the points from which the characteristic stinging pain could be evoked were very numerous. But, although the threshold was the same in the two cases, the sensation produced was much more unpleasant over the protopathic area. It radiated widely and was localized in remote parts; everything conduced to the impression that the pain was greater.

Thus, we may conclude that painful cutaneous stimuli produce a more unpleasant and more diffused sensation within highly protopathic areas than over normal parts. Moreover, this is the case even when such tests as the algesimeter and the pain-hairs show that the threshold of painful sensation still remains higher than normal.

Existence in the normal skin of what may be called "the sense of a point" renders difficult all comparison of the threshold for pain over normal and protopathic areas. As soon as a sharp point is brought into contact with the normal skin of the hand, a person recognizes that he is touched with a pointed object; even with the indicator of the algesimeter at zero, H. always knew that he was about to be pricked on the normal skin, although no actual pain was produced until it registered from 20 to 30 on the scale. Over protopathic parts this sense of a point was absent. Contact with the instrument produced no response, if jarring was avoided. With gradually increasing pressure, a diffuse sensation of pain slowly developed, preceded by no indication that the stimulus was a pointed object. This would certainly mislead an ordinary patient; but H. found with practice that he could recognize, over normal parts, when this sensation of a point changed to pain.

We have spoken of the wide diffusion of the painful sensation and of its tendency to be localized in parts widely remote from the point stimulated. This reference is not fortuitous, but stimulation of the same spot usually produced a sensation in the same remote area. Thus, the skin between the knuckles of the index and middle fingers was linked up in a remarkable manner with the dorsal aspect of the thumb, and an area in the neighbourhood of the wrist was peculiarly associated with sensations in the proximal part of the forearm. A full description of these referred sensations will be given in chapter VIII.

During the period of returning sensibility to prick, it was evident that some points within the affected area responded, whilst others remained insensitive. Recovery was not uniform, but the skin became dotted with spots sensitive to painful stimuli.

Von Frey has shown that within any chosen area of the normal skin certain points respond more readily to painful stimulation. A stiff hair of known bending strain will cause pain at some spots but not at others. By this means it is possible to measure the force necessary to cause pain in any part of the body. These small areas have been called pain-spots on the analogy of the well-known heat- and cold-spots. But they are in reality points of maximum sensibility to pain, and when von Frey states that a certain hair evokes sensation from the pain-spots of a particular area, he in no way denies that hairs of greater bending strain may cause pain at other points within it.

When we attempted to map out these maximum spots within an area of recovering sensibility, we met with many difficulties. Spots could be marked out which were sensitive to painful cutaneous stimuli; but on again testing the area, many of these spots would not react, and new sensitive points were found between them. Moreover, even those which seemed to be constant from day to day were easily fatigued, and consecutive stimulations rarely produced the same results. Thus, we prefer to say that sensibility to prick returned by means of small sensitive spots within the analgesic area; these increased in number as the innervation of the part improved.

Long after the back of the hand had become sensitive to prick, the high threshold for pain showed that its innervation was still defective. But nearly five years after the operation the threshold over the permanently protopathic area had fallen to normal. It might have been thought that this would have formed a perfect field for the investigation of pain-spots. Here 200 grm./mm.^{2} everywhere produced a painful sensation, resembling the sting of an insect. At some points, this was more intense than at others; but we were unable to mark out definite pain-spots with this stimulus. When we used 150 grm./mm.^{2}, pain was produced at some points but not at others, exactly as on the normal skin. Yet when these spots were tested from day to day, they were not constant. Sometimes they reacted to 150 grm./mm.^{2}, and sometimes they failed to respond. Here and there, we found a particularly active spot which sometimes reacted to 70 grm./mm.^{2}. By using hairs between 70 and 150 grm./mm.^{2}, this spot could generally be rediscovered, but not always with the same stimulus.

Thus it would seem, that, when a portion of the skin has long been sensitive to pain, but does not respond to tactile stimuli, spots of maximum sensibility may be found equivalent to those described by von Frey. But at no point is it certain that pain can not be produced by increasing the strength of the cutaneous stimulus.

In conclusion, we find that, during the greater part of the protopathic period of recovery, the threshold for cutaneous painful stimuli is higher than normal. But a small area on the back of H.'s hand has remained in this condition up to the present time (1908); here the threshold, measured with hairs of known bending strain, has sunk to normal. But in both cases, even when the protopathic sensibility of the affected area was demonstrably defective, the sensation of pain evoked radiated widely and was referred into remote parts. It was more unpleasant and was usually said to be "more painful" than the pain which followed application of the same stimulus to the normal skin. We believe that the sensation of pain evoked by punctate cutaneous stimuli is due to small sensitive areas in the skin analogous to the heat- and cold-spots. These vary greatly in activity and threshold, and the "Schmerzpunkte" of von Frey are the pain-spots of the lowest threshold in any particular part of the skin.

Section 3.—Heat and Cold.

No return of sensation to any form of thermal stimulus could be discovered on the forearm until August 15 (112 days after the operation). We then found that the proximal portion of the affected area was sensitive to ice-cold. The next day cold-spots had reappeared over these parts, but nowhere else within the affected area. Of these spots, four lay within the upper (proximal) forearm patch[1] and five over the dorsal aspect of the thumb; five responded uniformly, even to a drop of cold fluid, whilst four were what we have called spots of the second grade. It is therefore certain that the earliest return of sensibility to cold coincided with the reappearance of cold-spots.

A similar return of sensation (September 9) within the lower (distal) forearm patch[1] was associated with the reappearance of six cold-spots. When this area was stimulated with a cold test-tube, a sensation was experienced in the region of the metacarpal of the thumb. This is the phenomenon of "reference," which will be considered fully later. We found that this peculiar sensation at a distance could be evoked by stimulating a single cold-spot. The character of the reaction to widespread stimulation was the same as that of an isolated spot, additional evidence that the sensibility to cold depended on the reappearance of the cold-spots.

In the same way, the return of sensibility to cold in the neighbourhood of the base of the first phalanx of the thumb was associated with the appearance of a single cold-spot. On September 20, we found that whenever the silver test-tube fell within a certain area of about 1 cm. in diameter, it caused a brisk sensation of cold. On testing this part with the ice-cold rods, a single spot was discovered, to which the sensibility of the whole area was evidently due.

Over the lower part of the forearm, in the neighbourhood of the wrist, lay a triangular area, sensitive to cotton wool, but entirely insensitive to prick and to cold. On October 15, for the first time, a test-tube containing ice evoked a sensation of cold; this was due to the reappearance of a single cold-spot in the centre of the triangle.

Parts on the back of the hand, such as the interosseous space, first responded to cold on October 10. Here also the return of sensibility was coincident with the reappearance of cold-spots. Moreover, in consequence of the wide distances between them in this early stage of recovery, we were able to show that sensibility to cold was confined to the neighbourhood of the cold-spots; parts which lay between them were insensitive to all cold stimuli.

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[1] The area of disturbed sensation on the forearm could be divided roughly into three portions (fig. 7). The upper patch extended for about 2 in. (5 cm.) distal to the scar; this was followed by a more elongated patch, passing by means of a narrow neck into the anæsthetic area on the back of the hand. These will frequently be spoken of as the "upper" and "lower" forearm patches and the "neck."

The return of sensibility to heat was considerably delayed in comparison with that to cold; but its relation to the reappearance of heat-spots was strikingly evident. The sparsity of these organs, and the large area of skin between any two groups of heat-spots, make it peculiarly easy to prove that they are responsible for all the sensations of heat experienced during the protopathic period of returning sensibility.

Until October 8, heat produced no sensation anywhere within the affected area of the forearm or hand. But on this date, 166 days after the operation, tubes at 45° C. were occasionally said to be hot when applied to the upper patch on the forearm. Here a definite heat-spot was found to have made its appearance.

On November 1, the back of the hand reacted for the first time to temperatures above 45° C., in the neighbourhood of the head of the first metacarpal bone. Here a distinct spot was found which subsequently proved to be one of the most constant and active of all the heat-spots on H.'s hand. By November 9, a second spot had made its appearance, which reacted constantly and vividly, producing a sensation of warmth which radiated over the greater part of the first interosseous space.

From this time the total number of heat-spots increased greatly; but by January 25, 1904, the total number within the affected area on the back of the hand did not exceed fifteen. In the space between these spots it was easily shown that the skin was entirely insensitive to all degrees of heat (figs. 17 and 18).

It was evident that the return of thermal sensibility at this stage was entirely dependent on the existence of cold- and heat-spots. Owing to the complete absence of sensibility to such stimuli everywhere except in the neighbourhood of these spots, investigation of their reactions was particularly easy, and an enumeration of the characters of thermal sensibility in the protopathic stage becomes an account of their peculiar properties.

One of the difficulties associated with the investigation of punctate sensibility is the difference in the certainty and vividness with which the various spots react. Provided the conditions are favourable, some spots respond to every suitable stimulation, and H. learnt to recognize these

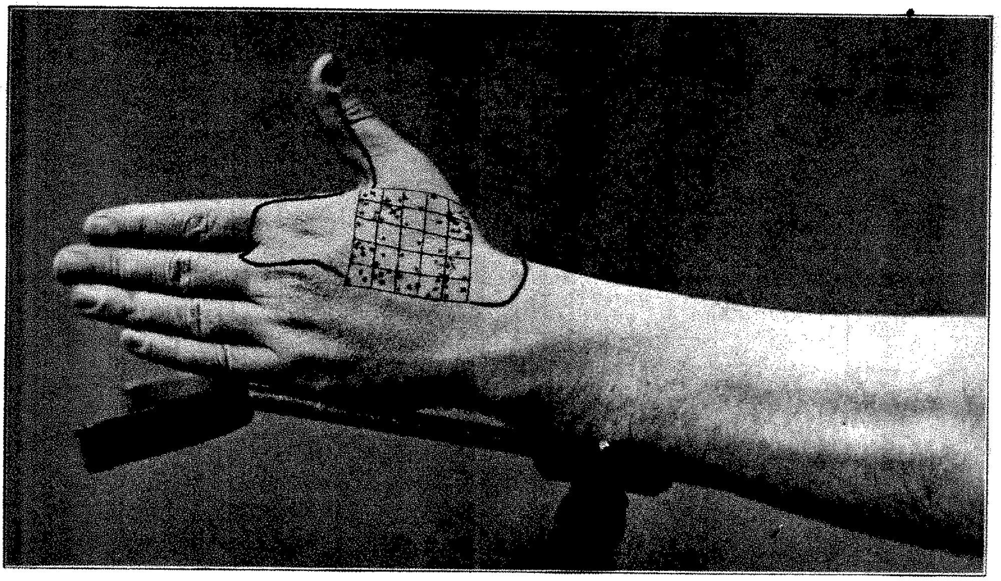

FIG. 17.

To show the photographic record taken on October 3, 1904, when the affected area of the hand was in a purely protopathic condition. Within the twenty-five squares each of 1 cm. the dots represent cold-spots, the crosses heat-spots. This photograph records the results of investigations which lasted six days.

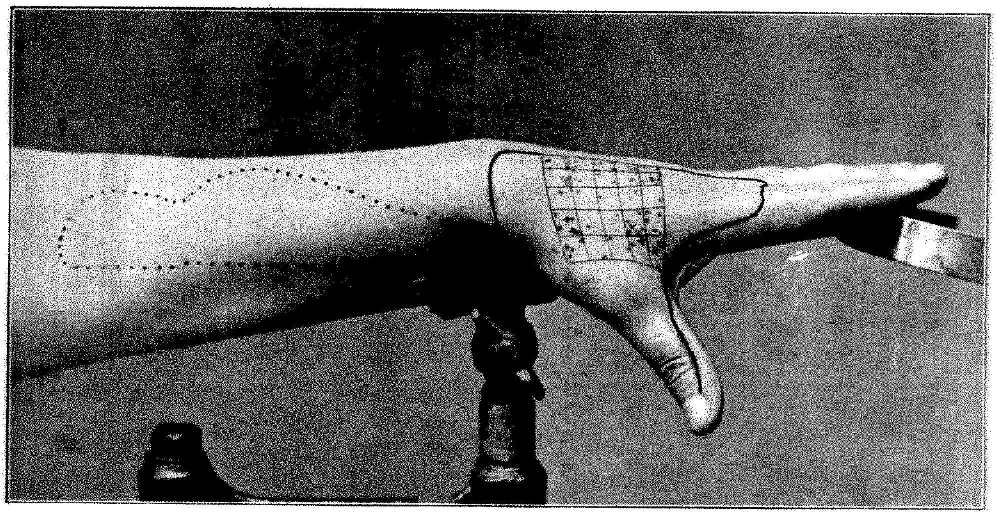

FIG. 18.

Lateral view of the hand taken on October 3, 1904

The dotted line encloses the area of diminished sensibility. The unbroken line on both figs. 17 and 18 encloses the parts in a condition of protopathic sensibility only.

first-grade spots, calling them by different names. They could be marked out with ease, whatever H.'s condition might be. But a considerable number of cold-spots responded with certainty only after a night's rest, when first stimulated, or when the rod had been recently removed from the ice. Such second-grade spots can be found over normal parts, but their discovery within a protopathic area is made easy by the total absence of any but punctate thermal sensibility.

Some of these second-grade spots will be found recorded on one photograph, some on another, and it is their existence which makes the marked area appear so different on various occasions. For instance, on a certain Saturday evening (July 9, 1904) all the cold-spots that could be discovered were those with which we had been familiar for many previous months. Next morning, we not only confirmed those marked out the night before, but obtained a response from a considerable number of other spots. On the third day, many but not all of these additional spots could be confirmed: but every one of those marked out on Saturday night, when H. was fatigued, responded readily throughout the whole sitting. Thus, it can never be said at any moment that all the cold-spots in existence have been marked. However carefully the squares may have been examined, it will always be found at another sitting under different conditions that some spots have escaped discovery and that some previously recorded no longer react. But, by extending the sittings over several days, and by preventing for long periods the disappearance of the marks on the back of the hand, we were able to show that at this stage of recovery, wide spaces existed where the skin never reacted to punctate thermal stimuli.

Von Frey long ago used a fine drop of ether, or even cold water, for discovering cold-spots, and we found that those of the first grade responded even to the drop of ink used to record their position. A spot was discovered by means of the ice-cold rod and then marked with coloured fluid at the temperature of the room. This produced a sensation of cold if the spot was an active one; the antecedent stimulation with the ice-cold rod did not exhaust a first-grade spot sufficiently to prevent an active response, even to so feeble a punctate stimulus as a drop of fluid at a temperature of about 13° C. to 18° C. This "reaction to marking" became, therefore, a useful criterion of the activity of any particular cold-spot.

Among the heat-spots we found fewer differences in activity. Most of them reacted constantly to suitable stimuli, and could be roused to activity time after time at short intervals. For instance, we never failed to discover those within the affected area in the adjacent angles of 26 E and 25 D. On the normal part of the back of H.'s left hand, a spot in the fourth interosseous space and the spot in the extreme upper corner of square 26 A responded on every occasion. So constant was this last spot that we were able to use it as a test for the accuracy with which we had marked the vertical base line of the system of squares (fig. 17, p. 375).

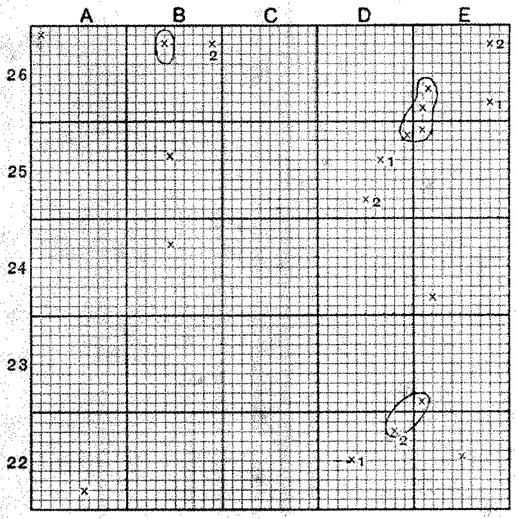

FIG. 19.

To show the position of the heat-spots within the twenty-five squares obtained by collating the eighteen photographic records.

Where a group of spots are enclosed they lie so thickly that sometimes one and sometimes another appeared on the photographs.

The numbers from 22 to 26 follow the longitudinal axis of the third metacarpal. The letters A to E lie directly at right angles across the back of the hand (*cf.* figs. 17 and 18).

The heat-spots are not only less numerous than the cold-spots, but they respond more constantly to suitable stimuli. Most of them are so isolated that their position can be rediscovered without difficulty and recorded with certainty. Some confusion arose at first in our records, because we did not recognize that some of the heat-spots lay in groups. Thus, in the adjacent angles of the squares 26 D and E, 25 D and E, lay a number of spots so close together that they were difficult to separate: sometimes one, sometimes another member of this constellation appeared in our photographs. In the same way, at the angle between 23 E and

22 D, lay spots which were sometimes recorded as lying in the extreme lower corner of the one or the extreme upper corner of the other square. But many like 26 A and 25 B lay completely isolated. Such spots were rediscovered or not according to the activity of their reaction; there was no doubt as to their position when once they responded to the warm point.

The most striking fact revealed by our photographic records, extending over nearly four years, is the large number of squares on the back of the hand from which heat-spots were uniformly absent. These squares remained totally insensitive to all degrees of heat, until after the return of sensibility to light touch. Out of the twenty-five squares, thirteen were completely devoid of heat-spots.

Fig. 19 shows the position of the heat-spots within the twenty-five squares on the back of the hand from photographs taken between the years 1904 and 1907. Many of them were recognized during the period of returning protopathic sensibility; but by April, 1904, twelve months after the operation, every heat-spot, with one exception, had been discovered. From this time we were unable to obtain any reaction to punctate heat stimuli from any part of this area in which a spot had not already been marked, and most of these heat-spots are easily demonstrable at the present time.

When we consider that these observations extended over four years, and were made under varying conditions of external temperature and bodily health, it is remarkable with what constancy many of these spots reacted.

By collating the photographs taken on eighteen occasions at the close of the observations, which were extended in some cases over weeks or even months, we obtained the following results:—

Of the sixteen positions shown on fig. 19, thirteen were marked out on ten or more of the photographic records as the site of an active heat-spot. Most of these are still easily discoverable, in spite of the return of sensibility to minor degrees of heat over the greater part of this area on the back of the hand.

	Present	Absent
Group at the angle of 26 E, 25 E and 25 D	18	0
26 A	18	0
25 B	17	1
26 E[1]	16	2
26 B[1]	15	3

	Present	Absent
25 D^1	15	3
22 E	14	4 (after Jan. 29, 1906)
24 E	13 consecutive times after discovery (Dec. 5, 1904)	
Group at the angle of 23 E and 22 D	13	5
Of this group 22 D^2 was	12	6
26 E^2	13 (1 doubtful)	5
26 B^2	11	7
25 D^2	10	8
24 B	8	10
22 D^1	5	13
22 A	5	13

It is difficult to make an analogous study of the distribution of the cold-spots on account of their greater number and the proportional increase of those of the second grade. This leads to a confusing diversity in the records. For when many cold-spots lie within each centimetre square, it is less possible to be certain of their identity than when it contains a single constellation. If two or three heat-spots are massed in the corner of a square, it matters little whether one or other of the group reacted on a particular occasion; they form an isolated unit in a wide area insensitive to heat. But it matters greatly if one member of a group of cold-spots was marked at one time, whilst a second one appeared on another record. A comparatively small diversity in response will materially change the relative position of the marked spot to the remaining groups within the same square and may make subsequent identification impossible.

On three occasions (October, 1904; March, 1906; and August, 1907), we not only made the usual photographic records of the spots which reacted at the time, but we also recorded on key-maps the site and characters of the various first-grade spots deduced from continuous observations extending over several weeks (fig. 20).

On collating these records, sixty-eight points in all were found to be marked as the site of cold-spots; of these, thirteen were present in all three sets of maps and photographs. But the uniformity with which these spots were recognized depends not only on the readiness with which they responded, but to some extent on their position. Two lying in close proximity to heat-spots of the first grade (26 A, 25 D) could never be missed. Others lay in some peculiar situation which made their recognition unusually easy. Thus, the square 24 E contained one spot only. But in a square such as 26 B it is obvious that several groups of cold-spots are present, some of which were marked at one time, some at another. Of these No. 3 alone could be recognized with certainty in all the records.

The average number of cold-spots within the twenty-five squares, obtained by collating the whole series of photographic records, is fifty-one. On the photograph taken in March, 1906, at the conclusion of a series of observations lasting over many weeks, the cold-spots numbered in all fifty-eight, of which twenty-eight were said to belong to the first grade. But these spots are so unevenly distributed that in most of the photographs seven squares contain none at all.

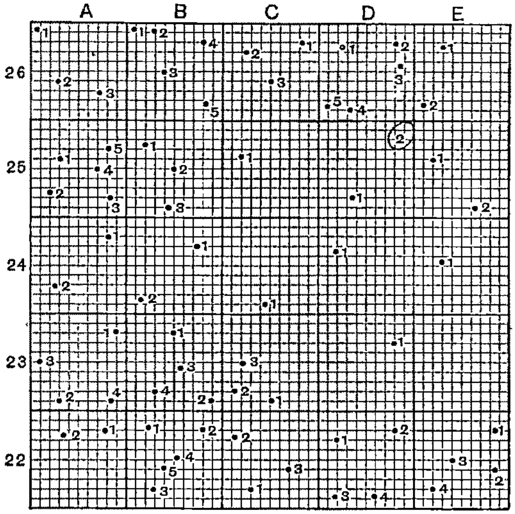

FIG. 20.

To show the position of the cold-spots within the twenty-five squares compiled from the records of October, 1904; March, 1906; and August, 1907.

General fatigue plays a considerable part in the ease with which a sensation can be evoked from temperature-spots even over normal parts. After a tiring day, H. was able to mark out those of the first grade only, and could obtain no reaction from the many second-grade spots which were easily discovered after a night's rest.

If first-grade spots are selected for examination, it is not difficult to show most of the phenomena of spot-sensibility on the normal skin. But in our case the demonstration was greatly facilitated by the entire absence of any temperature sensibility apart from spots.

The range to which heat- and cold-spots react varies considerably according to the temperature of the hand and to other conditions, of which fatigue is the most important. But at no time could we find a heat-spot from which any sensation could be evoked by any temperature below 37° C.

At first, few heat-spots responded to temperatures below 45° C.; but as recovery progressed, the first-grade spots began to react to 40° C. Two spots only were sensitive to 37° C. under favourable conditions. Even now that part of the back of the hand which remains in a condition of protopathic sensibility is still insensitive to temperatures below 37° C.; the temperature most favourable for evoking a sensation of uncomplicated heat still lies between about 44° C. and 48° C. At 50° C., a stinging is produced which complicates the purity of the sensation of heat by the introduction of a new element.

We wish to warn observers against the difficulties caused by using too high temperatures. Over a first-grade spot, 55° C. produces first a sensation of heat; this is accompanied by a peculiar tingling, foreign to spot-sensation in its pure form. It resembles more clearly the tingling produced by a mild but painful interrupted current. This sensation increases rapidly in intensity and ultimately ousts the warm sensation from consciousness. Finally, an intense pain is produced, in which H. can recognize no element of heat. This would not be called hot but for the antecedent sensation of warmth and for the fact that, in ordinary life, this painful sensation usually arises in consequence of excessive heat.

At about 50° C. the pleasant feeling-tone of spot-warmth is still obvious, in spite of the presence of a tingling which contains an element of discomfort, scarcely to be called pain. These sensations are as distinct as if a hot test-tube and an interrupted current were being applied together. At 52° C., this tingling rises in intensity and becomes decidedly painful. As soon as the temperature of the test-tube falls again to about 48° C., the tingling lessens and the pleasurable spot-heat reasserts itself as if a covering had been removed.

The properties of heat-spots can be investigated only by working with temperatures which do not evoke this accessory tingling. This caution, so necessary for all who work on the normal skin, is equally obligatory when examining parts in a condition of protopathic sensibility.

The highest temperature to which the cold-spots within the affected area reacted varied greatly. External cold, especially when associated with dampness and fog, greatly lowers the sensibility of the hand. No cold-spot reacted to temperatures above 26° C., even under the most favourable conditions, and few responded habitually to 25° C.

At first, during the earlier protopathic stages, no sensation of cold might be evoked by temperatures above 20° C.; but with rapid increase of this form of sensibility, the part became increasingly sensitive to temperatures up to 24° C. With this gradual improvement, the first-grade spots responded with increasing constancy to the same range of temperature.

Five years after the operation, an area between the knuckles of the index and middle fingers, though highly sensitive, still remains in a purely protopathic condition. Within its limits lie many active cold-spots, but not one of these reacts to temperatures above 26° C., and many scarcely react to 24° C.

When an area supplied with protopathic sensibility only is stimulated by means of a cold object, a sensation is evoked which differs greatly from that produced over the normal skin. When first the cold test-tube is applied, no result is produced; the sensation of cold makes its appearance after a short interval and slowly increases, until at last it possesses a quality of freezing, to an uncomfortable degree. On contact with a corresponding part of the normal skin the same tube is at once appreciated as cold. But the unpleasant quality does not reach the severity of that produced over the affected area. The difference between the response of the two parts consists, first, in the slower development of the sensation on the abnormal side, and, secondly, in the greater intensity of its unpleasant quality. This would certainly lead an ordinary patient to say that the sensation was "colder" on the affected side.

Not only has this sensation on a protopathic area a more unpleasant quality, but it is diffused over a wider extent. By stimulating a group of cold-spots with a drop of ether, it is possible to avoid all localization by way of deep sensibility. In this manner, we have obtained from a small group of spots the most intense sensation of cold not confined to the point stimulated, but affecting the greater part of the abnormal area on the back of the hand. This wide diffusion would also tend to make an unskilled observer say that the sensation produced from the protopathic area was "colder" than that from the normal skin.

Stimulation of an active heat-spot produced a response that could not be mistaken. The sensation seemed to flash up like a bright light in the darkness. From January, 1905, onwards, the area on the back of the hand was in a perfect condition for observing the difference between the effect of heat applied to these spots or to parts between them. Several first-grade spots lay in an area of about 5 cm. by 2 cm., which was totally insensitive to cotton wool after the hand had been shaved. Here no sensation was produced by heat, unless one of these spots was included within the area stimulated. Moreover, to be effective, the temperature must have been higher than 37° C.

But at this time the proximal part of the affected area on the back of the hand had already become sensitive to cotton wool and to von Frey's tactile hairs. Here a tube at 36° C. produced an immediate sensation of warmth; this gradually increased in intensity, and was strictly associated with the sensations of touch produced by the contact of the tube. Touch and warmth formed an entity, giving the impression of a single object.

Early in this research H. became conscious that he was frequently confused about the intensity of the cold of the stimulating object. A test-tube containing water at 20° C. would produce a sensation apparently colder than that caused by stimulating an active cold-spot with an ice-cold rod.

To investigate this condition, a group of active cold-spots was selected within a protopathic area, and one of them was stimulated with an ice-cold copper rod. After an interval, the bottom of a silver test-tube containing water at 19° C. was placed over the group of spots. H. invariably thought that the tube at 19° C. was "colder" than the iced rod. The two stimulations were repeated in irregular sequence, care being taken that a sufficient interval was allowed to elapse between them. Throughout these experiments H. was unable to recognize by means of his tactile sensations whether he was being stimulated by the tube or the rod; in one case, after the tube had been applied, he said, "That is a good spot," comparing it with the previous stimulation with the ice-cold rod. The test-tube in every case produced a far more extensive sensation, and H. said that this would certainly have been regarded as colder by the ordinary patient.

Within wide limits it would seem that the number of spots stimulated is of greater importance than the intensity of the cold by which the sensation is evoked. If the two objects are of equal area, the one which is of lower temperature will produce the more extensive sensation, and will therefore be called "colder." But an ice-cold rod, which can stimulate one cold-spot only, will seem less cold than a tube containing water that is only cool to the normal skin.

Another factor, which tells in the same direction, is the wide extent of the referred sensation produced by stimulating a protopathic area. Stimulation of a single spot with an ice-cold rod may produce coldness in a remote part; but excitation of a group of spots, even with a temperature of 20° C., causes a still more extensive referred sensation of cold. This will usually be called "colder" than the sensation produced by stimulating a single spot, however intense may be the cold employed.

Owing to the scattered position of the heat-spots on the back of the hand we were unable to perform the analogous experiment with any certainty.

If active cold-spots are stimulated with heat, a vivid sensation of cold is produced, exactly resembling that caused by a cold rod. This is the familiar phenomenon known as "paradox-cold," and can be demonstrated on the normal skin. But, over parts in a condition of protopathic sensibility, this peculiar reaction can be studied with an ease impossible elsewhere. The scattered distribution of the heat-spots and the absence of all sensibility to heat in the intervening spaces makes it possible to find large areas where the only parts sensitive to thermal stimuli are the cold-spots. Stimulation of these cold-spots with the copper soldering iron at any temperature above about 44° C. will evoke a vivid sensation of cold. Moreover, the sensation has the same qualities as that produced by the cold rod; it is widely diffused and tends to be referred into remote parts. If a certain group of cold-spots has a tendency to produce a sensation in some definite part at a distance, the paradox-cold will be referred to the same part.

In common with all other observers, we have been unable to produce an analogous sensation of heat by stimulating the heat-spots with a cold object. But the experimental conditions are entirely different in the two cases. When the hand was in a protopathic condition large areas could be found sensitive to cold only; but there was no heat-spot that was not surrounded by a constellation of cold-spots. It was therefore impossible to apply cold to a heat-spot on the back of the affected hand without at the same time stimulating one or more of the cold-spots which lay so thickly around it.

We were unable to convince ourselves that the prick of a fine needle, accurately thrust into the site of an active cold- or heat-spot, produced any thermal sensation. The same may be said of other forms of mechanical stimulation.

We attempted to discover whether these spots responded to electrical stimulation, but were greatly hampered by the difficulty that the electrode was in itself a cause of thermal stimulation. However, we overcame this source of error by using the head of a small pin which had been warmed to about 30° C. One pole of the coil was connected with the pin, the other with a large flat electrode upon which H. rested the palm of his hand. A shunt-key was placed in the circuit and was controlled by R. The minute testing electrode was placed over one of the active spots and, after we were certain that no thermal sensation was produced, R. opened and closed the key without H.'s knowledge. In no case was any true sensation of heat or cold produced. We must therefore conclude that these temperature-spots are insensitive equally to mechanical and electrical stimulation.

In conclusion, we believe that all sensibility to heat and cold, present during the protopathic stage of recovery, is due to the activity of heat- and cold-spots. Within the twenty-five squares of 1 cm. on the back of H.'s affected hand, we found sixteen heat-spots and an average of fifty-one cold-spots. The heat-spots did not react to temperatures below 37° C., and we found no cold-spot that responded to a cold stimulus at a temperature above 26° C. But paradox-cold can be evoked from the cold-spots of the normal and protopathic skin with punctate stimuli at temperatures between about 45° C. and 50° C.

Any thermal sensation produced by an adequate stimulus to a protopathic area tends to be widely diffused and to be referred into remote parts. In the attempt to estimate the relative intensity of two stimuli, a less cold object covering a larger area of the skin may evoke a more vivid sensation than one of smaller size but of lower temperature. H. invariably thought the former was "colder" than the latter; and yet if the two stimuli covered approximately the same area, he could recognize which of them was at the lower temperature.

Section 4.—Hair-Sensibility.

The hairs within the affected area of the forearm and hand remained totally insensitive to all forms of stimulation until July 20, 1903, eighty-six days after the operation. We then discovered that, within the upper patch on the forearm, lay four hairs from which a sensation was evoked by pulling. At a distinct interval after the hair was pulled, H. experienced a slowly developing vague sensation which was neither definitely painful nor unpleasant. It died away, and recurred as a painful sensation which faded, and again recurred as pain. The sensibility of these four hairs varied greatly ; but slow development and a tendency to recur were the most certain characteristics of the sensation evoked when they were stimulated. This mode of reaction of the hairs was the beginning of the gradual restitution of a certain form of sensibility

On the forearm and over the thumb, the return of painful sensibility was developed earlier and more widely to prick than to plucking the hairs. Over areas where few hairs were painful we found innumerable points where prick was distinctly appreciated. But there was no doubt that the upper patch on the forearm with a larger number of painful hairs was also more sensitive to prick than the more distal parts of the limb, where these hairs were less numerous.

On October 3, 1903, 161 days after the operation, we found that the affected area was no longer completely insensitive to cotton wool. Three days later, sensibility had so greatly increased that a sensation was evoked by cotton wool everywhere over the forearm. So curious and abnormal was its character, that the borders of the original anæsthetic area could be marked out precisely, by noting the point at which the sensation changed when cotton wool was dragged across the arm from normal to abnormal parts.

Throughout the period during which the hairs of the forearm were regaining their sensibility, the skin of the back of the hand had remained entirely insensitive. But on December 3, 222 days after the operation, the thumb and adjoining portion of the first interosseous space seemed to be sensitive to cotton wool. Three days later (December 6), cotton wool produced a definite sensation over the basal and terminal phalanges of the thumb, and over the back of the hand this stimulus was distinctly appreciated in many situations, especially within the first interosseous space. When stimuli were repeated at intervals of a few seconds, a diffuse general painless tingling resulted ; if a longer pause was allowed to elapse between them, the general tingling died away and was slowly renewed. H. was then unable to say exactly at what point of time the stimulus had been applied which had caused this renewal of the sensation.

Within less than a week (December 13), a few scattered hairs in the first interosseous space caused a painful sensation when pulled.

This sensibility of the hairs on the back of the hand rapidly increased. On January 4, 1904, 254 days after the operation, no part of the affected area which possessed hairs failed to respond.

This response was of the same extraordinary character as that with which we became familiar when testing the hairs of the forearm, and consisted of a general tingling. Not only was it diffused widely, but a sensation was evoked which seemed to lie over parts of the affected area remote from the point of stimulation. For instance, when the neighbourhood of the index knuckle was gently rubbed with cotton wool, a tingling was produced all over the metacarpal of the thumb. Moreover, if the hairs were pulled, the pain which resulted was also referred to the same remote parts as the sensation produced by stroking with cotton wool.

Here again we were face to face with the same tendency for a sensation to be referred to remote parts as was the case when a protopathic area was exposed to thermal or painful stimuli. Moreover, the sensation was referred to the same situation, whether the stimulus consisted of mechanical stimulation of the hairs, the prick of a pin, a hot or a cold test-tube.

Throughout the period during which the hairs of the forearm and hand had grown increasingly sensitive to pulling and to stimulation with cotton wool, the whole affected area had remained entirely insensitive to the careful application of No. 5 of von Frey's hairs. But if it was allowed to touch any part of the hairs which lay above the surface of the skin, the same diffuse tingling was produced as with any other mechanical stimulation.

Now, there is no part of the normal forearm or hand where No. 5 does not produce a sensation, if the point is placed on the windward side of a hair. For almost every hair is closely associated with one of von Frey's touch-points. The total failure of the affected area to react to No. 5 showed, either that the threshold was abnormally high, or that the hairs had become endowed with a form of sensibility independent of that usually called light cutaneous touch. The latter hypothesis seems to be the correct one. For when normal hair-clad parts are shaved, it is found that the skin, at any rate of the forearm and hand, remains sensitive to cotton wool.

But as soon as the affected area was shaved, cotton wool no longer produced a sensation of any kind, and the original anæsthetic borders could be marked out as accurately as on the day after the operation. The peculiar reaction we have described is therefore associated solely with the innervation of the hairs.

Fortunately, a small portion of the hairless skin of the thenar eminence was included within the anæsthetic area. In spite of the universal development of this tingling reaction to cotton wool over the hair-clad parts of the affected skin, this portion of the thenar eminence remained throughout the whole of this period insensitive to cotton wool and to von Frey's tactile hairs. When cotton wool was applied in such a way that it was distinctly appreciated over the normal parts of the thenar eminence, all sensation was lost in the neighbourhood of the boundary of the affected area. On moving the cotton wool further in the radial direction, the typical tingling sensation was evoked and the cotton wool was again appreciated, but in a new way. This was particularly well seen in the region of the head of the metacarpal of the thumb, where some long hairs tend to lie athwart the axis of the bone. As soon as the tips of these hairs were reached, H. called out, "Hair stimulation." He said, "I recognize the extreme difference between the two conditions. The skin of the normal thenar eminence gives rise to a sensation different from that produced by stimulating normal hair-clad parts. During the observations described above, this sensation ceased entirely for considerable periods" (these coincided with the stimulation by R. of the hairless insensitive portion of the thenar eminence). "Suddenly an entirely new sensation made its appearance which I have learnt to associate with the stimulation of hairs within the affected area. This is characterized by a diffuse tingling, and by extraordinary reference to parts at a distance."

The part of the skin of the hand which lies between the knuckle of the index and middle fingers still remains in a condition of protopathic sensibility. So long as the hairs are intact, cotton wool causes an unusually intense tingling sensation, but as soon as the part is shaved it becomes entirely insensitive to cotton wool. Whether the hairs are intact or not, careful stimulation with von Frey's No. 5 fails entirely to elicit any sensation; and yet, before the operation, there were many spots in this situation which reacted to this stimulus.

In conclusion, we find that the period of recovery associated with the existence of protopathic sensibility brings to the hairs a capacity for reacting to mechanical stimulation. But the resulting sensation is tingling and diffused, and tends to be referred to parts remote from the point stimulated. Moreover, the return of this form of sensibility does not bring to the skin after shaving any power of reacting to stimulation with cotton wool or von Frey's No. 5.

Section 5.—The Sensibility of the Glans penis.

At an early stage in our observations on the consequences of injury to peripheral nerves, we began to search the body to see if perhaps some part of the normal skin might exhibit protopathic characters. For if a protopathic response is associated with a more primitive form of sensibility, it was always possible that some area might have remained normally in this condition. We then discovered that the glans penis responded to cutaneous stimuli in that peculiar manner with which we were already familiar from our study of the first stage of recovery after nerve division.

On turning to von Frey's account of the glans penis ([9] p. 175) we found a brilliant description of a part endowed with protopathic and deep sensibility only. We can add nothing material to this remarkable description, but shall attempt to show how exactly in the case of H. the response of this organ to cutaneous stimuli corresponds to that of the highly protopathic area, which remains on the back of his hand.

The protected position of the glans hidden away under the foreskin has no fundamental bearing on the nature of its response. Observations on H. exactly corresponded with those obtained from another subject who had been circumcised many years ago.

The glans is entirely insensitive to stimulation with cotton wool and with the tactile hairs. This is expressed by von Frey in the statement that the threshold for mechanical stimulation has a high value; he continues: "Es stellte sich dabei heraus dass die hohe Reizschwelle bedingt ist durch das Fehlen der Druckpuncte. Der seinerzeit bestimmte Schwellenwerth ist die Schmerzschwelle."

As soon as hairs of greater bending strain, the so-called "pain-hairs," are used, the glans is found to be sensitive to from 70 to 90 grm./mm.^{2}. This produces a characteristic diffuse boring or stinging pain much more unpleasant than over the skin of the penis or foreskin; von Frey specially remarks that the pain is of a different character from that over the normal skin.

The abnormal behaviour of the glans to painful cutaneous stimuli is well shown by means of the algesimeter. When the needle was brought into contact with the skin, such as that of the body of the penis, H. was at once conscious that he was being touched with a pointed object. At a variable pressure of from 20° upwards, the sensation became one of pain. But when the instrument was applied to the glans no sensation was produced until it registered over 20°. Then, if a sensitive spot had been chosen, pain appeared and was so excessively unpleasant that H. cried out and started away. This pain was not localized, but radiated widely and seemed to be situated in the urethra as well as in the glans. If the point impinged on a less sensitive spot, pain might not be caused until the instrument registered 40°. In this case a distinct sensation of deep touch appeared at about 30°, which merged gradually into the characteristic diffuse pain as the pressure was increased.

In the same way, an interrupted current almost painless on the normal skin causes an aching, tingling sensation over the glans which is extremely unpleasant. The characteristic "whirring" sensation is absent and is replaced by a slowly increasing diffused pain.

The most remarkable peculiarities are shown in the behaviour of the glans to heat and cold. In the case of H., there appear to be no heat-spots except in the neighbourhood of the corona; the body and tip of the glans are entirely insensitive to heat. But cold-spots abound and paradox-cold can be as easily evoked as from the protopathic hand.

We therefore made a number of observations in the following manner. The foreskin was drawn back, and the penis allowed to hang downwards. A number of drinking glasses were prepared containing water at different temperatures. H. stood with his eyes closed, and R. gradually approached one of the glasses until the surface of the water covered the glans but did not touch the foreskin. Contact with the fluid was not appreciated; if, therefore, the temperature of the water was such that it did not produce a sensation of heat or cold, H. was unaware that anything had been done.

From 0° C. to 21° C. a sensation of cold was always produced which seemed "colder" than over the skin of the penis. Between 21° C. and 26° C. the answers were not uniform; sometimes the water was said to be cool, sometimes H. did not recognize that he had been stimulated. Above this temperature he uniformly failed to respond, although 27·5° C. seemed cool as soon as the water reached the foreskin.

With warm water at temperatures below 38° C., no sensation of any kind was produced until the foreskin was reached. At 38° C. H. complained of a slight aching, which increased in intensity until at about 43° C. it became extremely painful. At 45° C. the sensation was usually said to be cold. This is that paradox-cold, so frequent a phenomenon over the protopathic area on the back of the hand.

But if the glass was carefully raised, so that the water reached the neighbourhood of the corona without stimulating the frenulum or the foreskin, the same temperature was called pleasant heat. In the case of the other subject, heat-spots are present in the neighbourhood of the meatus, and temperatures above 40° C. were uniformly said to be warm.

So intense and widespread may be the sensation of cold or of heat, that von Frey speaks of the corona and neck of the glans as the most sensitive parts of the body to temperature. But these parts do not react to temperatures between 26° C. and 37° C. The threshold, judged by the range of reaction, is obviously raised, but judged by the intensity of the response, the part would be called one of increased sensibility to heat and cold. This is exactly the condition with which we are familiar, from our observations on the affected hand. The surface of the glans penis is a region highly endowed with protopathic sensibility.

But, in addition, the glans seems to have many of the characters of a part innervated from the deep system. If the needle of the algesimeter is replaced by a small piece of cork, no sensation is produced, until the instrument registers between 30° and 40°. This pressure, however, causes a distinct sensation of touch, which is usually well localized. As soon as the cork is withdrawn and the sharp needle substituted, pain is produced by this pressure, and the point of application cannot be localized with any approach to accuracy. We became familiar with this phenomenon when protopathic sensibility returned to the back of the hand already innervated from the deep system of afferent nerves. But the localization of tactile pressure on the glans is not of such a high order as over the hand endowed with deep sensibility only.

Another feature in which the glans resembles a part endowed with deep and protopathic sensibility is the absence of any appreciation of the relative size of the stimulating object. H. could not distinguish from one another a point, a rod with a circular base 2 mm. across, and one of 2 cm. diameter. But, as soon as they were applied with different pressures, whatever the size of the object, the greatest pressure was at once recognized. During the first of these observations, H. noted that he had experienced no pressure sensations so clear and definite since the days when the hand was innervated from the deep afferent fibres only. The definiteness of these sensations arose from the fact that they were uncomplicated by any accessory tactile phenomena.

In conclusion, we believe that the glans penis is an organ endowed with protopathic and deep sensibility only. It is not sensitive to cutaneous tactile stimuli, but pressure is correctly appreciated and localized with fair accuracy. Sensations of pain evoked by cutaneous stimulation are diffuse and more unpleasant than over normal parts. Sensibility to heat and cold is dependent entirely on the presence of heat- and cold-spots. If the former are absent from any part of the glans, temperatures of 45° C. produce a sensation of cold, indistinguishable from that caused by stimulation with a cold object. In every case the reaction appears to be more vivid than over normal parts, and yet the glans is entirely insensitive to temperatures between 26° C. and 37° C.

CHAPTER V.—EPICRITIC SENSIBILITY.

Section 1.—Tactile Sensibility.

Throughout the first year after the operation, the sensibility of the affected area to protopathic stimuli steadily increased, the response to a prick became more uniform, and the heat- and cold-spots more numerous. But it was not until 365 days after the operation (April 24, 1904), that the proximal part of the forearm first became sensitive to cotton wool when shaved. Nearly a fortnight before (April 17, 1904), we had discovered six spots within this area which responded to No. 5 of von Frey's hairs, even when care was taken to avoid contact with the projecting stumps of the hairs.

From this date, the forearm became increasingly sensitive to all cutaneous tactile stimuli. Step by step with this change, the tingling and referred sensations gradually diminished, until it was no longer possible to mark out with certainty the borders of the affected area on the forearm by means of cotton wool.

This disappearance of the tendency to refer into remote parts was the most striking sign of returning sensibility to tactile cutaneous stimuli. When the sensory condition of the forearm went back during the winter of 1904-5, this phenomenon reappeared as clearly as before. During every subsequent summer the sensibility improved, and every winter it tended to fall back somewhat. But at the end of four years after the operation, sensation had so completely returned to the forearm that it was no longer possible, even during the following winter, to discover any material abnormality in this part of the affected area. Brushing the hairs with cotton wool no longer caused a diffuse tingling and this stimulus was appreciated, even when the forearm was carefully shaved. Moreover, within the whole area, a multitude of points responded even to No. 3.

Owing to the detailed nature of our previous observations, we were able to watch the consequences of returning sensation on the back of the hand with greater minuteness. Here the first signs of sensibility to cotton wool after shaving appeared 567 days after the operation (November 12, 1904), in the neighbourhood of the radial aspect of the carpus and the proximal portion of the metacarpal of the thumb; these parts still remained insensitive to No. 5 (fig. 13). But though this response to cutaneous tactile stimuli was very defective, reference was profoundly inhibited. The sensation evoked was diffuse, but it was no longer situated in some remote part.

With the coming of the winter cold (December, 1904), the greater part of the recovering area on the hand again became insensitive to cotton wool after shaving, and the referred sensations were as definite as before.

It was not until March 26, 1905, that the small patch which had remained sensitive to tactile cutaneous stimuli, began to extend rapidly again in the direction of the thumb and first interosseous space. Over almost the whole of these parts, No. 5 was now appreciated. Steady improvement took place throughout the summer, and even the hairless portion of the thenar eminence which lay within the limits of the affected area became sensitive to tactile cutaneous stimuli.

Accurate localization of touches with cotton wool now became possible over the greater part of the back of the hand and the dorsal aspect of the thumb. Tingling and referred sensations ceased, except over the distal part of the affected area, which has not even now, five years after the operation, become sensitive to cotton wool after shaving (fig. 14).

At the present time, the back of the hand still presents two parts in different states of sensibility. The proximal part responds to cotton wool when shaved, to No. 5 and occasionally to No. 4 of the tactile hairs. This includes the basal phalanx of the thumb. The more distal portions of the affected area remain in a purely protopathic condition, entirely insensitive to cutaneous tactile stimuli (fig. 14).

In association with this gradual return of cutaneous tactile sensibility, H. regained the power of appreciating the "pointedness" of a needle or pin. Over normal parts of the hand, it is almost impossible to touch the skin with a sharp point, such as that of the algesimeter, without producing a sensation which betrays its pointed nature. This sensation is not painful, but conveys the impression that the stimulating object is sharp. It was totally absent from all parts in the purely protopathic condition. Even at the present time, the highly sensitive protopathic portion of the back of the hand is incapable of responding to the algesimeter, until it registers 30 or more degrees, and hairs of from 50 to 70 grm./mm.^{2} evoke sensation of pressure only.

This power of recognizing the sharpness of a stimulating object, underlying the discrimination of the head from the point of a pin, is a function of the appreciation of relative size. It is restored to the affected skin together with the sensation of cutaneous touch and other functions of epicritic sensibility.

Thus, when a part previously in a condition of protopathic sensibility begins to respond to cotton wool after careful shaving, the diffuse tingling diminishes, the sensation is no longer referred to remote parts, and correct localization becomes possible. At the same time, the power of distinguishing the point from the head of the pin and the appreciation of relative size are gradually restored.

Section 2.—Thermal Sensibility.

Returning sensibility of the skin to tactile stimuli was associated with a profound change in the response to heat and cold. Temperatures to which the protopathic parts were insensitive now evoked a sensation, and both radiation and reference of heat and cold ultimately disappeared entirely.

These changes could best be studied over the back of the hand; for during the eighteen months which preceded the first signs of returning epicritic sensibility, we had become familiar with the position of all the principal heat- and cold-spots within this part of the affected area. We shall therefore begin our account of the effect produced by the return of epicritic sensibility with a description of the thermal reactions on the hand, dealing later with the similar changes which occurred in the forearm at an earlier date.

Before the skin in the neighbourhood of the wrist had become sensitive to cotton wool, we noticed that temperatures of 36° C. or even 34° C. occasionally caused a sensation of warmth (October 23, 1904). This differed materially from the response obtained by stimulating heat-spots; it was well localized and seemed to develop in close association with the touch of the stimulating object. Moreover, it was evoked from parts where no heat-spots had ever been discovered. By November 12, 1904, temperatures of 36° C. produced an undoubted sensation of warmth over an area which included the site of the most sensitive group of heat-spots on the hand. But we found that, although the parts around now responded to 36° C., the spots themselves still failed to react to any temperature below 38° C.

The results obtained by stimulating this area with low temperatures were less striking, but seemed to point to the conclusion that an analogous change was taking place in the sensibility of the hand to cold. Temperatures of 26·5° C. and 25·5° C. were said to be cool in the neighbourhood of the wrist, although no other part of the affected area reacted at that time to anything above 24° C.

It was plain that certain parts of the back of the hand, especially in the neighbourhood of the wrist and over the metacarpal of the thumb, had become sensitive to temperatures, to which the remainder of the affected area, endowed with heat- and cold-spots only, did not respond. It was these same parts which about this time became sensitive to cotton wool when shaved.

Throughout the winter, the hand made little further progress towards recovery, and at one time seemed to fall back into an earlier condition. But, whenever the days were bright and the temperature more favourable, we were able to confirm the return of sensibility to temperatures between 33° C. and 37° C.

During this period, the hand was in an excellent condition for observing the difference between the sensations produced from a part innervated by heat-spots only and those due to stimulation of the recovering area with temperatures to which not even the most sensitive heat-spot reacted.

Over the centre of the back of the hand (26 and 25 B), lay a group of unusually active spots, within an area which did not otherwise respond to heat; here the skin was anæsthetic to cotton wool when shaved and to von Frey's tactile hairs. No temperature below 38° C. produced any sensation of heat, and higher degrees caused the characteristic response, radiating widely and referred to some remote part.

But, over the proximal portion of the first interosseous space and the head of the metacarpal of the thumb, lay an area sensitive to cutaneous tactile stimuli. Here 36° C. uniformly produced a sensation of warmth which was strictly associated with those of touch and pressure. Touch, pressure and warmth formed an entity, giving the impression of a single object. With higher temperatures such as 40° C. capable of stimulating the heat-spots in this region, this sensation of warmth merged gradually into pleasurable spot-heat. But this differed greatly from the response obtained on stimulating heat-spots over parts that had not entered on the final stage of recovery; for it was no longer referred to some remote part, but was closely associated with the other local sensations. The coming of the new reaction to warmth had not only increased the range of the sensitiveness of the skin to thermal stimuli, but had inhibited the tendency to refer into remote parts.

This part of the hand not only recovered its sensibility to less intense degrees of heat, but when the weather was favourable, temperatures of 27° C. began to be appreciated as cool. Throughout the greater part of the period of this experiment, the external temperature was seldom above 20° C., and the hand was always adapted to cold to a varying degree. But during the summer, especially of 1906, we made several observations which showed that the proximal part of the affected area on the hand responded to temperatures such as 27° C., to which the cold-spots never reacted.

This increased sensitiveness to thermal stimuli was not associated with any increase in the number of the heat- and cold-spots. In fact, it became evident with the return of sensibility to cutaneous tactile stimuli that many of the cold-spots were less easily marked out than before. During the purely protopathic stage of recovery, no sensibility to heat and cold existed, except in the position of the spots. They were therefore easier to mark out than when the intervening portions of the skin had become sensitive to the intermediate degrees of temperature.

But, apart from this technical difficulty, it seemed as if the increased sensibility diminished the activity of the temperature-spots. First-grade spots could be discovered as easily as before, although they no longer produced a widespread referred sensation; but those of the second grade were less numerous over the proximal squares on the hand than before this part responded to minor degrees of heat and cold. This was not due to any general change in the condition of the back of the hand, for the temperature-spots in the distal squares showed no diminution.

The diminished vividness of reaction, the increased range of sensibility and the inhibition of reference into remote parts were not due to an increase of the sensibility which had previously been present, but to the advent of a new sensory factor. This was proved by the experiment first made in May, 1905, of cooling the hand. We found that the mechanism upon which this new form of response depended was peculiarly susceptible to external cold.

After an extended series of observations, we placed the palm of the hand upon ice for a few minutes. It was then withdrawn and laid upon a towel as usual, and those parts from which no referred sensations had been obtained were again tested with an ice-cold tube. In every case, a sensation was evoked in some remote part as vivid and distinct as in the days before the hand became sensitive to intermediate degrees of temperature. External cold had thrown back the recovering area into a protopathic condition.

Before cooling the hand.	*After cooling the hand.*
(5) Local cold.	All over interosseous space.
(10) Local cold.	Up the arm to the scar.
(3) Local cold.	Head of first metacarpal and base of first phalanx of thumb.
(9) A diffuse sensation around the spot touched.	Metacarpal of thumb.

(The numbers represent the part to which the stimulus was applied, as shown on fig. 21, p. 414.)

By again warming the hand, the previous condition could be revived; reference disappeared from this part of the affected area which regained its sensibility to intermediate degrees of temperature. Further experiments on these lines will be described in chapter VII.

The affected area on the forearm first began to respond to temperatures between 37° C. and 34° C. in June, 1904. The sensation produced was not referred to some distant part, but was that of warmth localized to the point stimulated. At the same time, that portion of the forearm which had become increasingly sensitive no longer responded so vividly to temperatures below 22° C. Stimulation with 20° C. was frequently said to be neutral over the proximal patch, although definitely cold over the distal part of the forearm.

As the general sensibility of the forearm increased, spreading slowly in a distal direction, the response to temperatures between 18° C. and 40° C. became very erratic. A stage was reached in which the protopathic hand gave more definite results and would have been considered more sensitive than the forearm which had already advanced another stage to recovery. This was due to the diminished ease with which the full reaction could be evoked from the cold-spots, inhibited by the newly developed sensory function.

This disturbing uncertainty slowly passed away and the whole of the affected area on the forearm has become uniformly sensitive to temperatures above 35° C.; even 33° C., under favourable conditions, produces a sensation of warmth.

In conclusion, we found that the return of sensibility to cutaneous tactile stimuli was associated with a tendency to respond to temperatures between 26° C. and 37° C. This increase in thermal sensibility was not accompanied by an increase in number of the heat- and cold-spots. Radiation and reference into remote parts steadily diminished, and the sensations excited by a hot or cold object became closely associated with those produced by contact at the point of stimulation. During the recovery of epicritic thermal sensibility, the hand could be degraded by cooling into a purely protopathic condition; radiation and reference returned as vividly as before, to disappear on again warming the hand.

Section 3.—The Compass-Test.

Tactile discrimination was absent throughout the stage when the affected area of the forearm and hand was innervated by deep sensibility only. Two points applied simultaneously were not distinguished, and every application of the compasses was said to produce a single sensation. H. showed no tendency to speak of the contact of a single point as "two."

With the return of protopathic sensibility, the compass-records became extremely irregular; not only were two points said to be one, but one point was as frequently thought to be two. Over the normal skin, this tendency to "double ones" commonly appears just before the threshold is reached and a slight increase in the distance between the two points will produce a record entirely free from mistakes. But in the protopathic stage, however highly the skin is endowed with this form of sensibility, uncontrolled by epicritic impulses, the single point frequently produced a double sensation even although the double stimuli were made with the points 10 cm. apart.

At a later period of recovery, when part of the affected area had become sensitive to cutaneous tactile stimuli, this doubling of the single point rendered all attempts to obtain an accurate threshold impossible. We were, however, able to show that it was peculiarly liable to occur, when one point of the compasses fell over distal parts of the limb, which were in a less advanced stage of recovery. Thus, in the forearm better records were obtained when the single point was applied in the upper patch than in the lower (distal), although the double stimulations were always made over the same spots.

This phenomenon of "double ones," as it occurred during H.'s recovery, seemed to be based on several different conditions. Stimulation with a single point sometimes produced two equally distinct tactile sensations, or one was more distinct than the other. Lastly, the sensation was occasionally of wide longitudinal extent, and so gave the impression that it was caused by two points at a distance from one another.

At the same time, stimulation with two points was sometimes called "one," because it produced a single tactile sensation with no abnormal quality; or the sensation was that of one point which seemed abnormally heavy. This was extremely puzzling, because its singleness compelled H. to call it "one," although the additional heaviness led him to think that it must have been produced by two points.

These abnormalities seem to be due for the most part to the radiation and reference so characteristic of protopathic sensibility. In the case of the hand, where one part still remains in a protopathic condition, the records are still bad in proportion as one point of the compasses falls within the limits of this area. Moreover, on those occasions when the sensibility of the skin fell back into an active protopathic state, in consequence of unfavourable external conditions, the records even at 3 cm. became almost worthless.

In spite, however, of the difficulty caused by these "double ones," we could watch the gradual return of epicritic sensibility in the lowering of the threshold at which one and two points produced an indistinguishable sensation. In November, 1903, when the forearm was still in a purely protopathic condition, this limit was reached at 6 cm. Together with the return of sensibility to warmth in June, 1904, a change for the better in this respect came over the compass-records, and in August of the same year, the threshold at which the compass-stimuli became indistinguishable had sunk to 5 cm. Finally, in June, 1905, a formula was obtained—

$$4\ \text{cm.}\ \frac{1 \mid 9\ \text{R.}\ 1\ \text{W.}}{2 \mid 9\ \text{R.}\ 1\ \text{W.}}$$

—almost comparable with that from a similar part of the normal forearm—

$$4\ \text{cm.}\ \frac{1 \mid 9\ \text{R.}\ 1\ \text{W.}}{2 \mid 10\ \text{R.}}$$

But, although the threshold at which the stimuli of the compasses became indistinguishable was greatly lowered, every application of the test even at distances of 8 or 9 cm. produced records containing an unusual number of errors, both in the recognition of one and of two points. Over the normal forearm, no mistakes were made, until within about 2 cm. of the distance at which every stimulus was called "one." But over the abnormal area, even when it had been sensitive for more than three years to cutaneous tactile stimuli and to warmth below 37° C., a large number of single compass-stimulations were thought to be double. For instance, on August 25, 1907, we obtained the following formulæ:—

Affected forearm.	Normal forearm.
$6\ \text{cm.}\ \frac{1 \mid 7\ \text{R.}\ 3\ \text{W.}}{2 \mid 10\ \text{R.}}$	$\frac{1 \mid 10\ \text{R.}}{2 \mid 10\ \text{R.}}$

		Affected forearm.	Normal forearm.
5 cm.	1	6 R. 4 W.	9 R. 1 W.
	2	10 R.	9 R. 1 W.
4 cm.	1	10 R.	10 R.
	2	3 R. 7 W.	10 W.

In conclusion, we believe that spacial discrimination, as tested by the simultaneous application of two compass-points, is a function of epicritic sensibility. A protopathic condition of the skin leads to intense confusion, in consequence mainly of radiation and reference. The first effect on the compass-records of the return of epicritic sensibility is the reduction of the distance at which one and two compass-points produce a similar sensation. Then the erroneous "double ones" are gradually reduced in number. But, even at the end of five years after the operation, many errors of this kind were still present when the compasses are applied, even at a distance of 8 cm. over the abnormal area of the forearm.

Section 4.—The Sensibility of the Triangle.

A month after the operation, we discovered that a small triangular portion of the affected area near the wrist was in a remarkable condition, insensitive to a prick but responding to cutaneous tactile stimuli. We failed to recognize its existence until May 25, 1903, partly because its sensibility was defective even to those stimuli to which it responded, but principally owing to the condition of the skin produced by the antiseptics. As soon, however, as all bandages were removed and the forearm thoroughly cleansed of the epithelial flakes, the remarkable condition of this part of the forearm became evident.

From the first, there was no doubt concerning the main sensory characters of this area. It had the form roughly of a right-angled triangle with the base (3 cm.) towards the hand and the hypotenuse (4·5 cm.) on the extensor aspect of the wrist. The third side measured about 4 cm. in length (fig. 5).

Like all the rest of the affected area, it was obviously endowed with deep sensibility. Tactile pressure was appreciated and well localized. The sense of roughness, measured by Graham Brown's æsthesiometer, was equal to that of a similar area on the sound wrist.

But, unlike any other part within the borders of the loss of sensation, the skin was undoubtedly sensitive to cutaneous tactile stimuli; No. 5 of von Frey's hairs and, to a less extent, No. 4, were appreciated. Cotton wool produced a sensation indistinguishable from that over the normal skin, unaccompanied by tingling, diffusion or reference into remote parts. Gently blowing on the hairs through a tube was at once appreciated. Within this area, from the day of its discovery, the point could always be distinguished with certainty from the head of a pin, although the skin was entirely insensitive to cutaneous painful stimuli. Localization, not only of pressure but also of cutaneous tactile stimuli, was as good as on a similar part of the normal forearm.

The remarkable feature of this area was the complete absence of all sensibility to cutaneous painful stimuli. A prick produced no sensation of pain, although the stimulus was recognized as a point. Pulling the hairs, so sensitive to the slightest movement, caused no pain.

The anomalous condition could best be demonstrated by electrical stimulation. Strong interrupted currents unbearably painful over the normal skin produced the characteristic whirring sensation devoid of any element of pain. But if the coils were separated so that the current was just appreciated, the threshold was only slightly higher over the triangle than over the corresponding area on the normal skin. (Coil distance, normal 2·5 cm., triangle 4·5 cm.)

Thus, although this area responded to tactile stimuli, its sensibility was less than normal. Although No. 5 produced a distinct sensation within the triangle, No. 4 was frequently not appreciated; but over the normal wrist many spots responded, even to No. 2. A similar slight diminution of sensibility was shown in the results of the compass-test. Over the normal wrist, when the points were separated to 3 cm., H. made no mistakes in the twenty applications, and the threshold lay between 3 cm. and 2 cm. But, over the triangle under similar conditions, four mistakes were made at this distance:—

$$3\text{ cm. }\frac{1 \mid 8\text{ R. }2\text{ W.}}{2 \mid 8\text{ R. }2\text{ W.}}$$

When we turn to the observations on the thermal sensibility of this triangle, we are face to face with many difficulties. Our earlier experiments were made with ordinary test-tubes of glass, and it was not until August 15, when the sensory condition had materially changed, that we used silver tubes. Again, it was difficult to prevent radiation to normal parts when testing an area of this size. Moreover, we were not at this time fully alive to the importance of the external temperature; we did not recognize that in the climate of this country the hands are usually adapted to cold.

But, in spite of these defects, we can say with certainty that the triangle remained insensitive to all temperatures below 22° C., until the appearance of the first cold-spot (October 15, 1903). Careful and repeated examination with the cold rods and with test-tubes containing ice failed to elicit any sensation of cold from any part of this area.

Similarly, we could discover no signs of heat-spots until November 9, 1903. But one of the most remarkable features of this area was its response to heat, applied not to points but to areas of 1 or more centimetres in diameter. Temperatures of from about 42° C. to 48° C. were at once said to be warm. But if the tube was at 50° C. or above, it was either called a touch or was said to be slightly warm, passing quickly into neutral. Had the warmth, appreciated when the stimulus was at 42° C., been due to radiation, a tube at 50° C. or above would have produced it with even greater certainty. Time after time the relative temperature of two tubes at 44° C. and at 55° C. were compared, when the former was invariably said to be the hotter of the two.

So far the results of our observations are definite. But one of the greatest difficulties was the tendency which H. showed to call cold stimuli "warm" within the limits of the triangle. Whenever a thermal sensation was produced at all, it was one of warmth; some of the most satisfactory warm sensations were evoked by an ice-cold tube and yet, at this time, temperatures of 50° C. and above were not appreciated. Even in the later days, when the triangle had become sensitive to prick, these higher temperatures evoked a sensation of pain only.

The first change which occurred in the sensibility of this area was on July 10, 1903, seventy-six days after the operation; it then became sensitive to painful cutaneous stimuli, such as a prick and the painful interrupted current. But it did not respond with a sensation of cold to temperatures below 22° C. until October 15, 1903, 173 days after the operation, when the first cold-spot was discovered within its limits. The cold test-tube laid on the skin elsewhere within the triangle caused no sensation of cold. On November 9, 1903, 198 days after the operation, the first heat-spots made their appearance, and from that time onwards the return of sensibility took place rapidly.

But throughout the whole of this period, the sensations which returned were not diffused or referred into remote parts. They were not more but less vivid than normal and in no way resembled those evoked from the greater part of the forearm and hand which had assumed the protopathic condition.

Here, owing to a fortunate anatomical peculiarity, the operation had produced on a small area of skin a condition of dissociated sensibility which was the converse of that of the protopathic parts. It was sensitive to cutaneous tactile stimuli, but insensitive to those which would normally produce pain. Cold was not recognized, and temperatures above 50° C. were not appreciated; yet 42° C. to 49° C. seemed to produce a sensation of warmth, and were always said to be hotter than those of 50° C. and above.

CHAPTER VI.—TROPHIC, VASOMOTOR, AND PILOMOTOR CHANGES.

Section 1.—Vasomotor and Trophic Disturbances of the Skin.

Changes in the nutrition and vascular supply of the part are among the usual consequences of dividing peripheral nerves. But if the injury is accidental, motor and sensory fibres are commonly destroyed together and much of the atrophy is due to the paralysis of the muscles. Even changes in the growth of the nails may be produced by the consequent immobility of the limb (Head and Sherren [17], p. 263).

But in our experiment all these sources of error were eliminated. Afferent nerves were alone divided, and during the period when the arm was immobilized on a splint, H. could move his fingers freely.

Care had been taken during the operation to protect the back of the hand from mechanical injury and irritation by antiseptics. But four days afterwards (April 29), the analgesic portion began to assume a somewhat swollen appearance. The surface was rough and the skin appeared white owing to the adherence of epithelial scales; with a magnifying glass it had a peculiar translucent appearance. A week later, the skin over the radial half of the back of the hand and dorsal surface of the thumb had become inelastic and wrinkled like that of an old man. This want of elasticity produced a sensation as if the back of the thumb were covered with collodion. But in addition the superficial layers of epithelium had formed minute bran-like scales; the affected portion was drier than the normal skin and the cracks more evident. The whole area was of a slightly deeper red than the rest of the skin of the hand, and therefore showed clearly on the photograph taken at this time (fig. 1). The hairs were disordered and did not lie in sweeping masses; they stood up or lay in an irregular manner, each hair assuming a different direction. The extent of these changes corresponded exactly with the area insensitive to prick.

The insensitive parts did not sweat, and in the hot weather of July, 1903, the difference between the normal and affected portion of the hand was striking. The normal skin was soft, moist and velvety, whilst the abnormal area was dry and inelastic. If a needle was dragged across the back of the hand, the white marks produced by the scratch disappeared rapidly from the normal skin; over the affected portion they remained sometimes for several days as white powdery lines. Midge-bites, which occurred five days before, were still evident as pinkish round swellings, although those on the rest of the hand were no longer visible.

This dryness and absence of sweating began to disappear from the proximal part of the affected area 112 days after the operation, and they were no longer present over the forearm after 136 days. But the skin of the hand remained in an abnormal condition and did not cease to be dry until about 189 days after the operation (November 1, 1903). With this return of sweating, the hand lost the peculiar bluish colour which had characterized it throughout the first five months of the experiment (October 6, 1903).

Evidently the vaso-constrictor fibres and those which govern the sweating of the skin began to function 107 days after the operation and had regained their function even over the hand within 190 days.

In spite of these changes in the skin, the operation in no way affected the growth of the thumb-nail. Before the operation, the nails of both thumbs were marked with nitric acid and were found to be growing equally. Afterwards, they continued to grow equally, even when the affected area was supplied with deep sensibility only and throughout the whole period of protopathic recovery. The actual amount of growth varied considerably at different seasons of the year, but this variation affected the nails of both hands to the same extent.

In July, 1903, as the sequel to an extensive series of observations on the sensibility of the frozen hand, we noticed that a sore had appeared in the centre of the affected area, evidently the consequence of a cold burn produced by ethyl chloride. It seemed to start as a vesicle which had contained a minute quantity of fluid; the surface of this blister was removed in the course of washing and a raw surface was exposed. If protected, this sore tended to heal, but broke down again in consequence of the small injuries of ordinary life. Thus, any act which tightened the skin, such as grasping an oar or the handle-bar of a bicycle, opened the sore again after it had formed a scab. By taking the skin between the finger and thumb, serum and even blood could be expressed from its edges.

In this condition the sore remained until 152 days after the operation (September 24, 1903). It then showed signs of healing and became dry and scaly. From the periphery, epithelium appeared to be growing in. Speaking broadly, the surface which a fortnight before appeared callous and unlikely to heal was now healing soundly and normally. This was coincident with the return of sensibility to prick to that part of the skin within which lay the sore. But its extreme proximal edge still remained analgesic, and it was not until 185 days after the operation (October 27), that this part of the hand became sensitive to prick and this edge of the sore healed finally. The strict relation between the healing of this trophic ulcer and the return of sensibility to prick was evident.

Section 2.—*The Pilomotor Reflex.*

Throughout the period when the skin of the forearm and hand was completely insensitive, it was impossible to produce erection of the hairs within the affected area. Vigorous stimulation of the skin of the chest with ice or other means would start the condition known as "goose-skin" which usually spread to both arms (Mackenzie [21]). Over the sound limb, all the hairs would be more or less erected, but on the left forearm, those of the affected area remained unchanged; this probably accounted for their disordered appearance.

With the return of protopathic sensibility, we noticed that the hairs could again be erected by suitable pilomotor stimuli. The exact date of the return of this reflex was not noted; but we gradually became aware that pricking the skin, pulling the hairs, or the application of the cold tube would occasionally give rise to a condition of "goose-skin" within the area we were testing.

As protopathic sensibility increased, this reflex could be evoked more easily from the affected area than from the normal skin. The iced tube placed on any active protopathic part might produce a widespread erection of the hairs over both the flexor and extensor aspect of the forearm which not infrequently spread beyond the limits of the area of defective sensibility. Even brushing the hairs with cotton wool in this stage of recovery would start a pilomotor reflex.

With the gradual return of epicritic sensibility to the forearm, this increased response died away, and at the present time it is no more easy to produce a pilomotor reflex from the affected area of the forearm than from other parts.

It is evident that the existence of a high degree of protopathic sensibility renders it easier to evoke a pilomotor effect. This excessive response is inhibited on the return of epicritic impulses.

Although stimulation of a protopathic area evoked a stronger pilomotor response, the erection of the hairs within this area was no greater than elsewhere, if the reflex was a general one produced by placing ice upon the chest. The increased effect caused by stimulating a protopathic area must therefore have been due to physiological conditions affecting its afferent impulses and not to any structural change in the central mechanism. Absence of that control usually produced by the coincident activity of epicritic impulses allowed those from the protopathic area to exercise a greater influence upon the central pilomotor mechanism. Had the excessive reaction been due to an anatomical change in the centre, a reflex evoked by general means, such as ice applied to the chest, would have produced a greater erection of hairs over the affected area than elsewhere; this was not the case.

During the period when the back of the hand was in a condition of active protopathic sensibility, we noticed that a referred sensation was liable to be associated with erection of the hairs over the remote area in which it was situated. Thus, pricking the region near the wrist would produce not only a sensation, but also erection of the hairs of the forearm near the scar. If the stimulus produced a severe protopathic reaction, this pilomotor reflex would become general; but if slighter, it tended to appear at the site of the referred sensation.

Whilst engaged on these experiments, we discovered that the "thrill" called forth by æsthetic pleasure is accompanied by erection of the hairs. In H.'s case, it started in the region of the neck and spread rapidly down the arms, over the trunk, the thighs and outer aspect of the legs. If he sat with his arms bared to the shoulder in a carefully warmed room he could evoke the reflex by reading aloud some favourite poem. At a certain point he would call out that the thrill was beginning and shortly afterwards the long hairs on both forearms were seen to be erected, and the characteristic acuminate appearance was noticed upon the skin. This general pilomotor reflex was no greater over the highly protopathic area than elsewhere on the arms.

CHAPTER VII.—ADAPTATION TO HEAT AND COLD.

After we had convinced ourselves by repeated experiment that the affected hand behaved differently in the winter and in the summer, we attempted, by changing its temperature, to alter its reaction to thermal stimuli. We found that, by laying the palm of the hand upon ice, we could throw back the greater part of the affected area into the protopathic condition. Cold had so reduced the sensibility of the skin that parts, which had almost returned to the normal condition, reacted as if they were in an earlier stage of recovery.

This led us on to examine the behaviour of the affected area when adapted to moderate degrees of heat and cold. If one hand is dipped into warm water, the other into cold, the same object at an intermediate temperature will seem cold to the former and warm to the latter. This is the well-known experiment on adaptation. We modified it by adapting both hands to the same temperatures and comparing the sensation produced by the same object over normal and abnormal parts.

The majority of these observations were made at sittings between December 2, 1906, and March 24, 1907. By a fortunate chance, the external temperature was on every occasion almost exactly the same; the highest reading was 14° C., the lowest 13° C. All these experiments, therefore, were begun with the hands adapted to a temperature of from 13° C. to 14° C.

Throughout the following experiments, two regions within the affected area were distinguished by their behaviour: (1) a purely protopathic part in the neighbourhood of the second metacarpal and occupying the space between the knuckles of the index and middle fingers; (2) that portion of the affected area, already far on towards recovery, which lay over the wrist and first metacarpal bone. But, since the latter behaved throughout like a normal area of lowered sensibility, attention will be directed mainly to the sensations produced from the protopathic parts of the affected hand.

The simplest form of the experiment was carried out in the following way. By preliminary observations, we found that a copper block at a temperature of 29° C. did not appear hot or cold over any part of either hand. Both hands were then placed in a basin of water at 50° C. After a time, they were removed, dried and placed in the usual position for testing. The stimulus at 29° C. now seemed cold when applied to the right hand and to the normal parts of the left, and cool over the metacarpal portion of the affected area. But elsewhere over this part of the hand, it produced no sensation of either heat or cold. So definite was this absence of sensation, that it could be used to mark out the boundaries of the affected area.

The hands were then put into water containing melting ice. When they were removed, the copper block at 29° C. seemed warm over the right hand and over normal parts of the left. Within the affected area, it produced no thermal sensation, excepting over the metacarpal portion, where it seemed to be warm.

This experiment shows that the thermal sensibility of protopathic parts did not undergo that shifting of threshold, which can make a temperature of 29° C. seem at one time hot and at another cold.

But the threshold of thermal sensibility over protopathic parts may shift, although not to this extreme degree. We therefore carried out a series of observations of which the most complete were made on March 2, 1907. The external temperature was 14° C. The hands were adapted to water at 45° C., removed from the basin and dried; after a few observations, they were returned to the basin, within which the water was kept at a constant temperature. Thus, they could be maintained in a condition of warm adaptation for the long period necessary for the following observations. In this condition 33° C. was found to give a neutral sensation over the normal hand and over normal parts of the left hand; temperatures of 30° C., 31° C. and 31·5° C. were called "cool neutral," and 29° C. seemed definitely cold. But over the protopathic area, none of these temperatures gave any thermal sensation. Cold was not evoked until the temperature was reduced below 24° C.

Over the right hand and normal parts of the left, 35° C. was said to be "warm neutral"; but 37° C. seemed definitely warm, even at a distance from heat-spots. Within the affected area, no sensation of heat was produced, until the stimulus reached 41° C., when it caused a characteristic outburst over the group of heat-spots in squares 26 B, 26 E, and 25 D; elsewhere it caused no sensation.

Thus, when the hands were warm-adapted (45° C.), the neutral point over normal parts seemed to lie at about 33° C. Temperatures of 29° C. were said to be definitely "cold," and 31·5° C. was called "cold neutral." At the opposite end of the scale, 35° C. produced a sensation of warmth which rose to definite heat at 37° C. But over protopathic parts, no temperature above 24° C. caused a sensation of cold, and no sensation of heat was produced by any temperature below 40° C. Moreover, whether the stimulus seemed to be hot or cold, the sensation had the characters of that evoked from spots.

When the hands were adapted to water at 13° C., 27° C. was found to be neutral everywhere over normal parts; 28° C. and all temperatures above seemed definitely warm. But over the protopathic area, no sensation of heat was produced until the stimulus reached from 39° C. to 41° C. A temperature of 20° C. evoked a sensation of cold from both normal and affected parts of the hand.

If the water in which the hands are adapted was lowered to 10° C., it occasionally happened under suitable conditions that a temperature of 22° C. seemed neutral over normal parts, but caused a definite outburst of spot-cold when applied to the affected area. We thus produced the paradoxical result, that parts of low general sensibility reacted definitely to temperatures which produced no sensation over the normal skin.

These experiments on cold adaptation are more difficult to carry out than those in which the hand is warmed. Throughout a great part of the year, the external temperature is so low that the exposed parts of the body are permanently adapted to cold. An attempt further to lower the temperature of the hand may cause it to become blue and cold, and lead to a serious diminution of general sensibility which frustrates the object of the experiment. Even 18° C. may then produce no sensation of cold over the affected area or any other part of the hand, the cold-spots may react feebly to temperatures that are usually effective and the intensity of the referred sensation is diminished.

Thus, dipping the hand into cold water may produce three separate conditions according to circumstances. Firstly, over normal parts a simple shifting of threshold may take place ; secondly, a part on the way to recovery and showing definite signs of epicritic sensibility may be thrust back to a purely protopathic condition as described on p. 396. Thirdly, especially in winter when the hand tends to be constantly cold-adapted, the application of severe cold may produce a condition of lowered general vitality, which diminishes the reaction, even of protopathic parts.

When the normal hand is adapted to heat, 33° C. becomes the neutral point, 35° C. seems to be warm and 31° C. cool. Carefully adapted to cold, the neutral point shifts to 27° C. and all temperatures above 28° C. are said to be warm.

Now, the highest temperature to which the cold-spots reacted was 26° C., and most of them did not respond to 24° C. Even when the hand was adapted to heat, no sensation was produced by any higher temperature. It is therefore evident, that some mechanism other than the cold-spots must exist in the normal skin by which a sensation of cold is evoked with temperatures between 24° C. and 31° C.

In the same way, when carefully adapted to cold, 28° C. may seem warm to the normal hand; yet the purely protopathic part never responded to temperatures below 37° C. and most heat-spots are insensitive to temperatures below 40° C. It is equally evident that there must be a mechanism other than the heat-spots by which sensations of warmth can be evoked with temperatures between 28° C. and 37° C.

These observations remove the difficulty experienced by Head and Sherren ([17], p. 224) in proving the existence of the sensation of coolness, apart from the reaction of cold-spots. Under the usual conditions, working with hospital patients, they could obtain no sensation of cold with temperatures above 24° C., and they found that even protopathic parts would respond to such stimuli under favourable conditions. But we have shown that, by adapting the hand to heat, there is a range of at least 5° C. above the highest limit of the cold-spots, within which stimulation of normal parts may produce a sensation of cold.

These observations may be summed up in the following conclusions :—

(1) Over normal parts, the neutral point of thermal sensibility shifts according as the hand is adapted to heat or to cold.

Over protopathic parts, no such change occurs. The heat-spots do not react to temperatures below 37° C., even when the hand is adapted to cold, nor does adaptation to heat raise the highest limit of the cold-spots above 26° C.

(2) It follows that some innervation other than protopathic must exist in the normal skin, which renders it sensitive to temperatures between 26° C. and 37° C., and that this mechanism is capable of adaptation within a wide range.

(3) By carefully adapting the hand to cold, a paradoxical condition can be reached, in which a temperature of 22° C. produces no sensation of cold over normal parts, although it evokes a definite sensation from the affected area. This is due to the fact that protopathic parts are incapable of adaptation to any material extent, and the cold-spots continue to react to 22° C., although it produces little or no sensation over the normal cold-adapted hand. By this experiment, parts in a condition of defective sensibility have been rendered apparently more sensitive to the specific stimulus of cold.[1]

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[1] The significance of these experiments depends upon the supposition that the normal and abnormal parts of the hand do not assume materially different temperatures after cooling and warming. To investigate this not improbable source of error we obtained the help of Dr. Bayliss, who kindly carried out with us a series of experiments on the temperature of the skin with a thermo-electric junction, in the Physiological Laboratory at University College. We tested the temperature of the dorsal surface of the hands after they had been warmed in water at 45° C. and cooled in water at 15° C. Two areas were chosen on each hand, one in the first and the other in the fourth interosseous space. By this means we tested on the left hand the behaviour of a normal against an abnormal area of skin; but, lest these two spots should naturally behave differently to warming and cooling, we carried out a series of tests over similar spots on the right hand. The results showed that the small differences in the temperature of the normal and abnormal parts after warming and cooling, lay within the limits of experimental error. The following table gives the results obtained in the most satisfactory series :—

	First interosseous space.	Fourth interosseous space.
Left hand.		
Cooled in water at 15° C.	19·2	19·2
Warmed in water at 45° C.	30·4	31·4
Right hand.		
Cooled in water at 15° C.	20·1	19·4
Warmed in water at 45° C.	31·8	31·6

CHAPTER VIII.—LOCALIZATION AND SPACIAL DISCRIMINATION.

Among the many curious facts elicited by this inquiry, none are more remarkable than those bearing on localization. At the time when the affected area was innervated by the afferent fibres of muscular nerves only, tactile pressure was localized accurately, although two points simultaneously applied to the skin could not be discriminated. Then followed the period when protopathic sensibility returned, and cutaneous stimuli began to be localized over some area at a distance from the point of impact. Slowly, with the return of epicritic sensibility, the power of accurate localization of cutaneous stimuli was restored.

Each of these conditions has been described in its proper place; but many of our observations are of such psychological interest, that we have deemed them worthy of more detailed consideration.

(1) *Deep Sensibility.*

After division of all the nerves to any area of the skin, the part is supplied solely with deep sensibility. A touch made with a certain amount of pressure can be localized with remarkable accuracy. At first, our observations were complicated by the unsatisfactory condition of the skin; but as soon as the œdema and swelling had passed away, we could not discover any obvious difference in the accuracy with which tactile pressure could be localized over corresponding parts of the two hands. H. visualizes strongly[1] and his accurate localization over the affected area was best shown when he was asked to mark the spot touched on a life-sized photograph of his hand (figs. 15 and 16.) Moreover, when allowed to indicate the place that had been touched, his answers were as accurate on the one hand as on the other, though his eyes remained closed throughout.

But in spite of this he could not discriminate two points applied simultaneously to the skin, even when separated to the greatest distance possible over the affected area on the back of the hand. Two points applied successively were at once recognized, even when 1·5 cm. distant from one another.

All appreciation of size and shape was lost over this area; the flat of a knife could not be distinguished from its edge, nor the head from the point of a pin. When a very large surface was applied to the back of the hand, H. thought it seemed to him large, because he had a visual picture of his hand upon which were certain points of reference such as the index knuckle and head of the first metacarpal. It was not possible to apply a large surface to the affected area in such a way that these points of reference would be stimulated simultaneously; and even a small interval between the moments at which different parts of the stimulating surface came into contact with the skin was sufficient to evoke the picture of two points. If these points were widely distant from one another, H. judged that the object must be of large size. But the more nearly the various distant parts of the affected area were touched at the same moment, the less was he able to recognize the extent of the surface stimulated.

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[1] On p. 343 stress was laid on the difficulties which arise, in consequence of the inability of a strong visualizer to reproduce cutaneous sensations. But throughout these experiments on localization and spacial discrimination, H. localized every sensation on a visual picture which corresponded remarkably with the proportions of the normal hand. This gave his answers a definiteness and security, unattainable when the quality of the sensation was in question.

Deep sensibility conveys the power of appreciating the locality of the part pressed upon, but not the ability to discriminate two points applied to the skin simultaneously. Nor does it convey any of those sensory qualities which underlie the appreciation of size and shape.

Head and Sherren ([17], p. 214) were able to show that, if a part possessed deep sensibility only, the position and movements of the joints could be accurately recognized. This question did not come to direct experiment in the case of H., but we can be certain from cases of accidental injury that the presence of deep sensibility enables the patient not only to localize the spot touched but to recognize the position of his limbs in space.

(2) *Protopathic Sensibility.*

So long as the affected area was innervated by the afferent fibres of muscular nerves only, the position of a touch was well localized. But with the first signs of returning protopathic sensibility, localization became gravely disturbed. This disturbance took two forms. The sensation seemed to be diffused to a varying extent round the point actually stimulated, and for this phenomenon we have throughout this paper used the term "radiation." In the other form there was produced a sensation also diffuse, but situated in a region remote from the point stimulated; this phenomenon we term "reference." Cold or a prick applied to the forearm not only radiated widely but produced a sensation in the thumb, and H. could no longer recognize which part of the affected area had been stimulated. With the return of cutaneous painful and thermal sensations, the power of localization, previously sufficiently accurate, was greatly disturbed.

As protopathic sensibility improved, the radiation greatly increased, and the tendency to refer the sensation into remote parts became more definite. H. was conscious of a struggle between the local sensations, evoked by the pressure of a cold tube, and the coldness which seemed to be situated in some part at a distance from the point stimulated. In the early days of returning protopathic sensibility, the former was dominant, and correct localization was possible, in spite of the radiating and remote sensations of tingling, cold or pain. Later, when protopathic sensibility had reached a high stage of development, this was no longer the case, unless the tube was applied with considerable pressure to the skin.

To evade the localization due to deep sensibility, we employed minute drops of ether or of ethyl chloride, instead of the ice-cold tube; the characteristic radiating and referred sensations of cold then appeared unhampered by the consequences of pressure. Such a stimulus applied to the wrist might cause the whole affected area on the back of the hand, including the greater part of the thumb, to become icy cold, and stimulation of a group of spots on the forearm was followed by an intense coldness over the whole dorsal surface of the thumb.

In these experiments, H. was in every case unconscious of the actual place of stimulation. He sat with his eyes closed, and in consequence of the even temperature of the room experienced no spontaneous sensations from the hand. Gradually out of this state of quiescence arose a more or less definite sensation of cold, entirely free from any element of touch, pain or tingling. This seemed to be situated over an area of considerable size, and was never limited to a point corresponding with that actually covered by the stimulus. There was no consciousness of anything in contact with the skin; the sensation was one of pure cold, and corresponded with nothing previously experienced by H.

The relative intensity of the radiating sensation and of that referred to some remote part varied greatly. But in every instance, the stimulus, however little tactile its character, was accompanied by some diffuse sensation in a situation approximate to the point stimulated. In some cases this might be so faint compared with the vivid reference that it scarcely aroused consciousness; on the other hand, the disturbance around the site of the stimulus might be so great that the remote sensation would have escaped notice without careful introspection.

To test the constancy of this reference, eleven situations were chosen over the back of the hand and marked on a life-sized photograph.

These situations were repeatedly tested between January, 1904, and the end of 1907 with every form of stimulus to which protopathic sensibility responds (fig. 21).

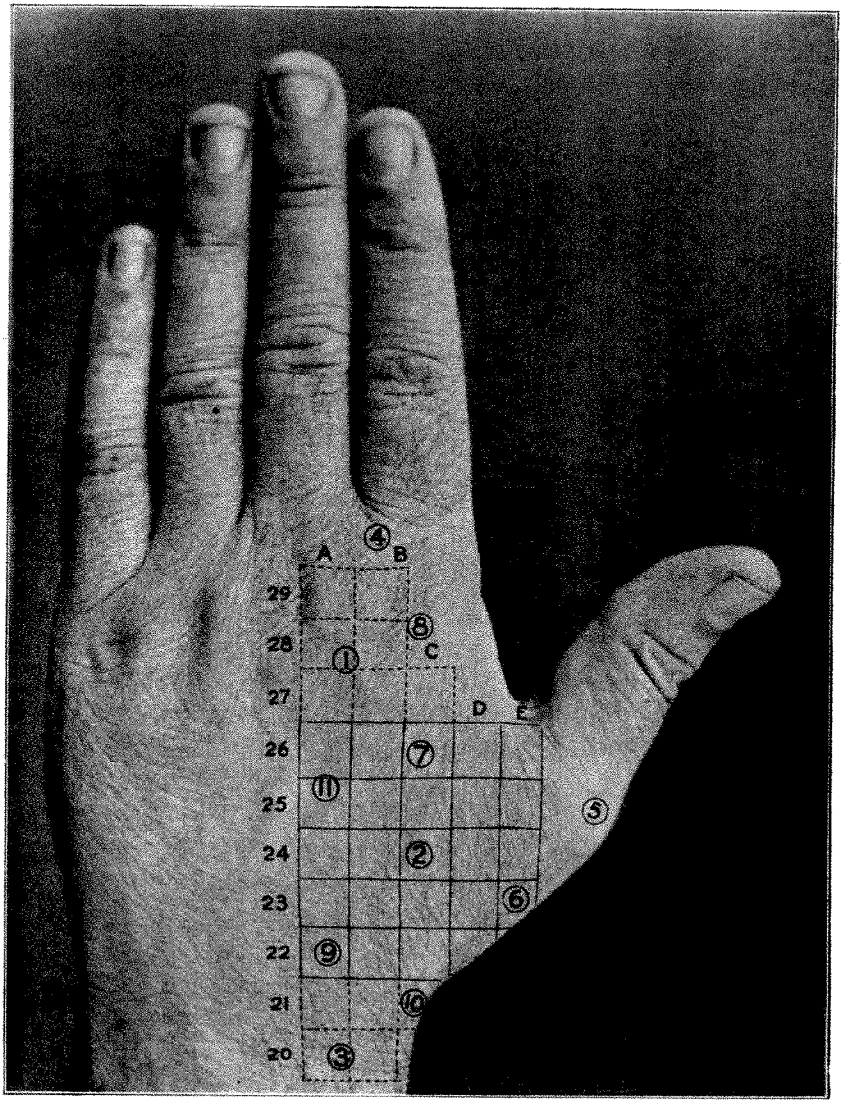

FIG. 21.

The circular numbered areas show the spots habitually stimulated when investigating the position of the referred sensation.

The squares marked in unbroken lines are those used throughout the whole research. Those enclosed within dotted lines were used to determine the position of the referred sensation when stimulating isolated heat- and cold-spots.

The back of the hand was also marked out into squares, and the position of the referred sensation determined for each square centimetre (fig. 21).

Of all stimuli, cold gave the best results; for it could be applied exactly to any point, whilst with cotton wool the rubbing backwards and forwards was liable to stimulate hairs which belonged to areas not directly over the situation desired. Pricking was also unsatisfactory, because of the duration of its after-effect and the prolonged diminution of sensibility by which a vigorous reaction to this stimulus was followed. Pulling the hairs was also comparatively unsatisfactory for the same reasons.

The eleven situations selected within the affected area on the back of the hand were tested on thirty-seven occasions with cotton wool, thirty-five times by stimulation with an ice-cold tube, six times with the prick of a pin, and four times by pulling hairs.

As a general rule, the constancy of reference was greater in the case of the cold tube than with cotton wool; this probably depends on the difficulty in limiting the latter mode of stimulation in every case to the same spot. In order to study reference, cold was always evoked by placing the flat end of the silver tube on the skin, so that the area covered was well defined and accurately limited to the region it was intended to stimulate. Cotton wool, however, had to be swept over the skin with some vigour, in order to elicit a sensation of sufficient intensity to provoke distinct reference, and, though every endeavour was made to limit the extent of the stimulus, it must have been usually wider than the area covered by the bottom of the cold tube. Further, even if the spot actually touched with cotton wool were strictly limited, the area of skin affected would be considerably larger, owing to the slope of the hairs; for a touch on one spot may, by moving a hair, actually stimulate a part of the skin 1 cm. or 2 cm. distant. The extent of the referred sensation was usually greater with cotton wool than with the cold tube, although the latter was a more intense stimulus. This must certainly have been due to the larger area stimulated by the cotton wool.

Of all the situations chosen (fig. 21), No. 10 lying close to the extensor tendons of the thumb, produced the most constant referred sensation. When stimulated with cotton wool, a characteristic tingling was produced in that part of the forearm which has been called the upper patch and lies in the neighbourhood of the distal end of the scar. Radiation was present around the wrist, but reference occurred invariably to the forearm. A cold test-tube produced equally constant results: on the twenty occasions upon which a referred sensation was evoked, it was situated in the same part of the forearm. Here no confusion was possible between radiation and reference. The one sensation seemed to be widely distributed over the back of the wrist within the affected area, whilst the other lay in the proximal part of the forearm.

No. 1, lying between the knuckles of the index and middle fingers, was another area from which reference to a remote part was almost constant. Forty-four times (twenty with cotton wool and twenty-four with cold) some portion of the thumb or its metacarpal was the seat of the referred sensation; twice only was it said to be over the radial aspect of the first interosseous space.

Stimulation of the two neighbouring situations, No. 8 and No. 4, gave results of almost equal constancy. In the case of the former, reference took place to the metacarpal of the thumb in forty-six instances (twenty-two with cotton wool, twenty-four with cold), and ten times to the radial aspect of the interosseous space, whilst stimulation of No. 8 was followed in fifty-three cases (twenty-six with cotton wool, twenty-seven with cold) by reference to the metacarpal or some part of the thumb; eight times to the radial aspect of the space and once to the wrist.

The two phalanges of the thumb lay outside the situations originally chosen, but have lately been the subject of an extended study in connexion with the conflict of referred and local sensations. The terminal phalanx is in the case of H. entirely devoid of hairs and could not be stimulated with cotton wool in its purely protopathic condition. But with cold and with heat, the referred sensation was in every case situated over the region between the knuckles of the index and middle fingers.

Reference from the basal phalanx of the thumb took place invariably to the same part; but when the fold of skin over the interphalangeal joint was stimulated, the sensation was referred occasionally to the wrist or to the index knuckle.

Less constant results were produced by stimulating the remaining situations on the back of the hand. One cause of this discrepancy, especially in the earlier observations, was the failure to distinguish between radiation and reference. As H. was in all cases ignorant of the actual position of the point stimulated, except in as far as he was guided by accompanying sensations of pressure, he was frequently unable to distinguish the two sensations. But, if the radiation and reference were widely separated, as when stimulation of the index knuckle produced a sensation in the thumb, no confusion was possible; it was from such situations that the answers were found to be most constant.

Moreover, several of the chosen situations seem to lie within areas which may refer to two different places. This is well illustrated by the results obtained from stimulating No. 3 on the dorsal surface of the wrist. On twenty-two occasions, the remote sensation seemed to be situated in the first metacarpal, and twelve times in the basal phalanx, making in all thirty-four times to some part of the thumb. But a definite referred sensation to the forearm was produced nineteen times from the same spot. We found that by shifting the tube slightly we were able to change the position of the referred coldness from the thumb to the forearm. Evidently No. 3 lay in the neighbourhood of two areas, one of which tends to be associated with reference to the thumb, the other to the forearm.

By combining all our observations, made by stimulating chosen situations or squares marked on the back of the hand, it appears that reference takes place somewhat as follows. The area on fig. 22 I. refers usually to some part of the forearm, that on fig. 22 III. tends to refer mainly into the thumb, and the whole thumb including a small portion of the radial half of the first interosseous space is associated with reference to the region of the index knuckle. In the same way, stimulation of the proximal patch on the forearm (fig. 22 IV. A) tended to evoke a sensation in the back of the hand, and the distal area (fig. 22 IV. B) was similarly associated with the skin over the base of the metacarpal of the thumb.

As far as we could tell, the various specific sense-organs, cold-spots, heat-spots and pain-hairs situated in any small area of the skin were associated with sensations referred to the same remote parts. Heat-spots were so scattered and so few in number that the material for such a generalization was scanty. But whenever the heat-spot was active, it was found that the sensation of heat was referred to the same area as the coldness produced by stimulating the adjacent cold-spots.

Stimulation of the area on the dorsal aspect of the thumb, shown on fig. 22 II., caused a sensation referred to the distal and ulnar aspect of the affected area on the back of the hand. Conversely, stimulation of this region of the skin (fig. 22 III.) caused a referred sensation in the thumb. So constant was this cross reference that it could be utilized for a series of experiments on inhibition.

During the earlier stages of recovery, we were not sufficiently aware of the constancy of this cross reference. But we were repeatedly struck with the tendency of the proximal part of the affected area on the forearm (fig. 22 IV. A) to be associated with the area on the back of the hand; similarly, stimulation of the distal portion of the affected forearm (fig. 22 IV. B) tended to be associated with a sensation over the metacarpal of the thumb. We were, however, unable to work out this relation so completely on the forearm as on the hand, for by the time reference from the hand to the forearm was fully established, recovery had so far advanced that the forearm no longer produced a referred sensation.

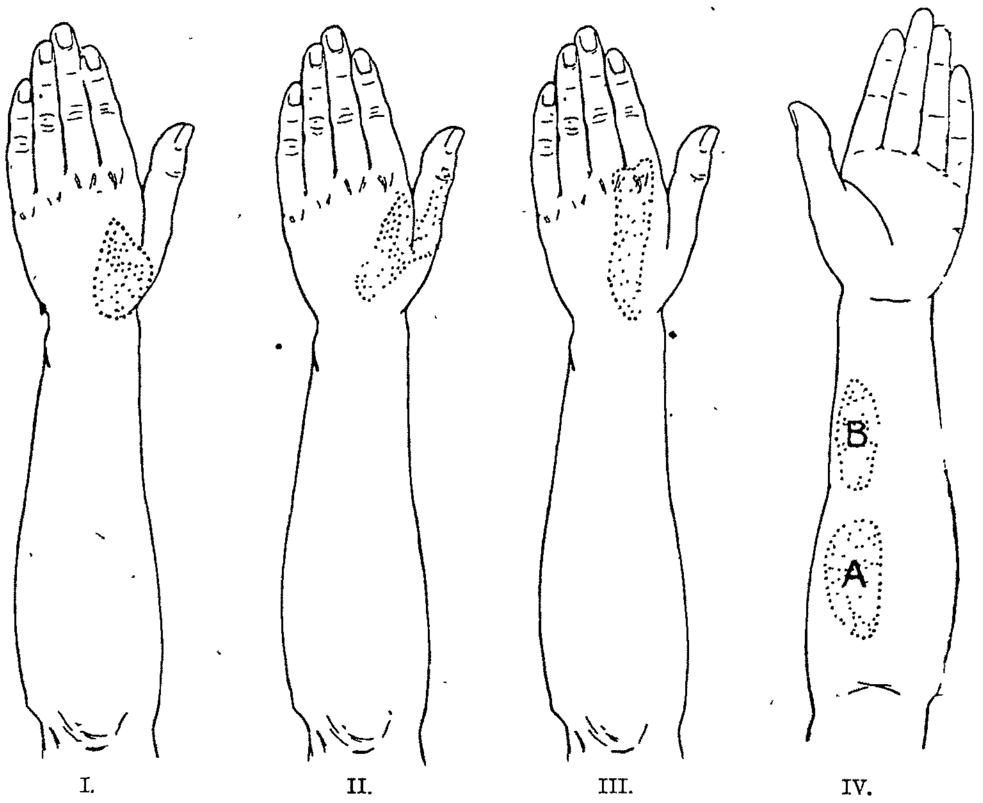

FIG. 22.

By marking out the whole of the dorsum of the hand with squares we found that stimulation of the area shown on I. caused a referred sensation in the forearm in the neighbourhood of IV A.

Stimulation of the area shown on II. caused a referred sensation in the region of the index knuckle

Stimulation of the area shown on III. caused a sensation in the thumb

Stimulation of the area marked A on IV. evoked a sensation over the dorsal surface of the hand near the wrist and that of B caused a referred sensation in the thumb.

Throughout this long series of observations, reference was always to a part within the affected area; it never lay over any normal part of the hand. Long after the forearm had returned so nearly to a condition of normal sensibility that stimulation with cold was no longer associated with reference, it was still possible to produce a sensation in the forearm by stimulating the back of the wrist. The parts over the metacarpal of the thumb have so far regained sensibility that no remote sensation can now be induced by stimulating the skin. But this part of the hand is still the seat of vivid referred sensations, whenever the ulnar and distal portions of the affected area are stimulated with cold or with cotton wool.

Throughout the whole period of protopathic recovery, localization was profoundly changed. At the same time, all spacial discrimination was absent, including all recognition of relative size. The results obtained with the compass-points were even less accurate than when the hand was innervated by deep sensibility only. Then the contact of a single point was rarely said to be two; but in the protopathic stage this occurred repeatedly. The application of a single point not only evoked a widespread tingling, but also in many cases a distinct remote sensation which greatly confused the answers to the compass-test.

(3) *Epicritic Sensibility.*

With the first signs of returning epicritic sensibility, reference occurred less frequently and radiation became diminished.

In the early part of November, 1904, when the shaved hand first became sensitive to cotton wool, it was found that a change had come over the nature of the reaction to an ice-cold tube; the sensation radiated widely around the spot stimulated, but was referred less than usual to remote situations. From those parts, however, which showed no return of epicritic sensibility, such as the neighbourhood of the index knuckle, the referred sensation was as vehement as ever.

In December of the same year, the sensibility of the hand went back in consequence of the winter cold; radiation and reference were as vivid as in the purely protopathic condition, and little if any of the affected portion of the hand was sensitive to cotton wool after shaving. In February, 1905, there was not a single situation within the affected area from which we did not obtain a referred sensation. From No. 10 near the wrist it was projected into the upper patch on the forearm as intensely as before.

With the coming of spring (April, 1905), seven out of the twelve situations gave local radiation without reference on stimulation with the ice-cold tube. There was coincident improvement of sensibility to cotton wool, and the results of the compass-test were the best so far recorded.

In June, 1905, the hand had further improved and a referred sensation was obtained on stimulation of the parts near the index knuckle only. Sensibility of the shaved hand to cotton wool had greatly increased, and the compass-test gave good results at 4 cm. when the points were placed longitudinally so as to fall as much as possible within the area of partial recovery.

Sensibility again degraded during the winter of 1905-6, accompanied by the reappearance of the phenomena of reference and widespread radiation. We therefore had the opportunity of confirming and amplifying our previous observations. But it is not necessary to wait for these annual fluctuations of temperature; artificial cooling will produce similar changes in the sensibility of the recovering parts. On July 6, 1905, reference was almost entirely absent and radiation greatly diminished. But after the palm of the left hand had been laid upon ice for a short time a referred sensation could be evoked from every situation within the affected area; even stimulation of the parts near the wrist was associated with coldness or tingling in the forearm. Similar changes were observed throughout the long series of experiments on adaptation made during the winter of 1906-7.

The inhibition of reference and radiation, which accompanies the return of epicritic sensibility, is evidently due to the opening up of fresh paths in the peripheral nervous system. The mechanism associated with protopathic sensibility is not gradually educated into something higher; but the consequences of its peculiar activity are checked in the central nervous system by the coincident existence of epicritic impulses. Inhibited and controlled, they are ready to burst out in the form of radiation and reference, as soon as the activity of the dominant mechanism is diminished by cooling the hand.

We therefore determined to test this control, by placing an ice-cold tube partly within and partly without the protopathic area on the back of the hand. The distal part of the affected area was still in an actively protopathic condition during the winter of 1907. It was separated from normal skin by a well-defined border almost coincident with the line of the third metacarpal bone. Here we could place an ice-cold tube so that the circular area of its base might be distributed in varying proportion between parts of normal and abnormal sensibility. When the tube was placed so that one half fell on the normal, the other on the abnormal side of the border in the region of square 27 A, a vivid coldness appeared in the thumb which disappeared, and was replaced by an entirely local sensation. Reference was wiped out as completely as if a current had been switched off. Sometimes the remote sensation reappeared in a fainter form to be abolished again completely.

This control of radiation and reference cannot be definitely said to be associated with any one factor in epicritic sensibility. The change occurred with the first signs that the affected hand was sensitive to warmth and to cotton wool after shaving. The compass-test still gave poor results at 6 cm.; but it must be remembered that the extent of skin to which epicritic sensibility was returning was at first so situated that the two points of the compasses could not be placed simultaneously within it. Later, we always found that row D gave uniformly better results than row B, which shows that with returning sensibility to warmth and to cotton wool after shaving came an increased power of spacial discrimination. This is the only new spacial faculty restored by the recovery of epicritic sensibility. Tactile localization and the sense of passive position were present from the beginning of the experiment; spacial discrimination alone was absent. If therefore the disappearance of radiation and reference is to be associated with any one element of epicritic sensibility, it is probably spacial discrimination which is responsible for the cessation of the abnormally wide diffusion of protopathic sensations.

The results at which we have arrived in this chapter may be summed up as follows:—

(1) Accurate tactile localization is possible even when the part is supplied with deep sensibility only, provided the pressure is sufficient to stimulate the deep afferent system.

Accurate localization of cutaneous stimuli does not return until the skin becomes sensitive to von Frey's tactile hairs and to cotton wool after shaving.

(2) It is possible to recognize the position of the parts in space and to appreciate the movement of the joints even though the limb is innervated by deep sensibility only.

(3) Tactile discrimination, the recognition of two compass-points applied simultaneously to the skin, is impossible in the absence of epicritic sensibility, except at distances enormously in excess of the normal.

(4) The protopathic condition is associated with a tendency to produce sensations in parts remote from the point of stimulation. If care

is taken to avoid tactile pressure, it may be impossible to recognize to what part of the skin the stimulus has been actually applied.

The existence of epicritic impulses inhibits this tendency to refer into remote parts. Thus, the first signs of returning sensibility to cutaneous touch and to minor degrees of heat led to a diminution of these referred sensations. In the same way, the return of sensation to prick and to the extremes of heat and cold to a part such as the triangle, previously sensitive to cutaneous tactile stimuli, was not associated with any tendency to reference. Even coincident stimulation of an adjacent part in the normal condition seems to have an inhibiting effect on this tendency of the protopathic skin.

(5) Localization is in all probability the sum of two sets of sensations, one of which arises from deep, the other from cutaneous stimulation. But with the remaining spacial elements the conditions are somewhat different. Deep sensibility is responsible for our knowledge of the position of our limbs in space, whilst stimulation of the epicritic system is necessary to evoke the power of spacial discrimination. Each of the two systems brings its addition to the impulses which underlie localization; but sense of position in space depends on deep sensibility alone, spacial discrimination on the activity of the epicritic system only.

CHAPTER IX.—INTENSITY.

Throughout the previous chapters, we have repeatedly dwelt on the vivid response of protopathic sensibility to painful stimuli. A prick, which on the normal skin gives rise to little more than a sensation of sharpness, may in the protopathic condition produce a response so unpleasant that it would in ordinary language be said to be much more painful.[1] We have little doubt that the trained psychologist experiencing the two sensations would say that the pain in the second case was of greater intensity, and, if speaking in terms of the sensibility of the skin, he would say that in the protopathic condition, it was more sensitive. On exact examination, he would expect to find that the skin had a lower threshold for pain, *i.e.*, that pain would be produced with a smaller stimulus than over normal parts.

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[1] All unpleasant protopathic sensations are associated with an unusually disagreeable feeling-tone. Those which are pleasant, such as the heat evoked by stimulating heat-spots, are unusually agreeable. Thus a temperature of 40° C. applied to a part devoid of heat-spots is less distinctly pleasant than when it is brought to bear on a group of active heat-spots in a protopathic area. Conversely, pain evoked even from a protopathic area of defective sensibility is more disagreeable than that produced by the same stimulus applied to the normal skin. In addition to pain, which is a measurable sensation, we must distinguish discomfort ("Unlust"). In cases of injury to the spinal cord discomfort may be produced over a totally analgesic area by potentially painful stimuli (*vide* Head and Thompson [18], p. 644).

Observations made with the algesimeter and with von Frey's pain-hairs have shown that this is not the case. The increased response to painful stimuli may even occur with a threshold considerably raised.

For, during a considerable part of the five years that have elapsed since the operation, the back of the hand was in a condition of low protopathic sensibility. Not only was the skin insensitive to such stimuli as light touch and warmth, but even painful sensations had a higher threshold than over normal parts. Yet in spite of the incomplete restoration of protopathic sensibility, the response to painful cutaneous stimuli was greater than normal. If attention is paid to the character of the sensation resulting from an equal stimulus to similar parts on the two hands, the affected area would seem to be more sensitive on account of the greater painfulness. But if the sensibility of the skin was measured by the threshold of stimulation, the affected area would be called less sensitive than normal.

This difference came out clearly, when the point of a pin was dragged across the back of the hand from normal to protopathic parts. The change was so sudden and the new sensation so painful, that the border could be marked out to within 2 mm. And yet at the same time the threshold for painful stimuli was higher than normal over the affected area.

It might be supposed that the exaggerated response of protopathic pain was due to some incomplete restoration of the functions of the mechanism for painful sensations, which would diminish or pass away with the lowering of the threshold to the normal. But this is not the case. Fortunately, a small part of the affected area still remains in a purely protopathic condition. Here the threshold for painful cutaneous stimuli does not materially differ from that over a similar part of the normal hand. But the sensations evoked from the affected area are still both more unpleasant and of greater extent than normal. The approximation of the threshold for painful stimulation to that over normal parts, far from decreasing, seems actually to have increased the vividness, the extent and the unpleasantness of the resulting sensation.

And yet H., like all patients in this condition, never for a moment doubts that the protopathic area is one of defective sensibility. Over normal parts of the hand, it is almost impossible to touch the skin with a sharp point, however lightly, without producing a sensation which he knows if increased will gradually pass into pain. The normal skin responds to a point with a sensation which is not painful, but which conveys the impression that the stimulating object is sharp. This is absent over protopathic parts. When the needle of the algesimeter is applied carefully, even over a highly sensitive protopathic area, the pressure can be increased without evoking any response until the scale shows about 20°. Then a sensation of pressure is evoked in consequence of the stimulus to deep sensibility. Increase the pressure further and at about 30° to 35° pain is produced, either suddenly or as a gradually increasing ache.

The sensibility of the protopathic area in the neighbourhood of the index knuckle (fig. 14) has so greatly increased, that the threshold for cutaneous painful sensations, tested with von Frey's hairs, is now the same as that of a similar part of the normal hand. But although the threshold for pain over this highly protopathic part has sunk to the normal, the sensibility of the two areas, tested by means of a sharp point, is fundamentally different. From the skin in a protopathic condition, pain is evoked without the preliminary painless sensation of a point.

These observations show that we must readjust the usual psychological conception of intensity, at any rate as far as painful sensibility is concerned.

On turning to the phenomena of thermal sensibility, many facts point to an equal need for revision of the usual views on intensity. On comparing the sensations from normal and protopathic parts, the same cold tube at 20° C. is commonly said to be colder over the affected area. But, if the threshold be determined in the usual way by lowering the temperature of the stimulus from neutral to the just perceptibly cold, it will be found that the protopathic region will seem to be by far less sensitive. A temperature of 30° C. or even 31° C. may be called cool over normal parts under favourable conditions, but 27° C. never produced a sensation of cold over any portion of the affected area. A part which reacted with a more vivid sensation of cold when stimulated with 20° C. was incapable of responding to temperatures well within the range of the normal skin.

Return of epicritic sensibility diminishes the vividness of response to protopathic stimuli. The part of the affected area in the neighbourhood of the first metacarpal has become sensitive to light touch after shaving and responds to minor degrees of heat; sensibility is almost completely restored. Temperatures of 26° C. and 27° C. produce a sensation of coldness and, measured by all the usual criteria, it is a highly sensitive part. But a tube at 20° C. seems less cold than over the neighbouring purely protopathic area.

The same condition was repeatedly observed throughout the period during which the forearm was recovering. Thus, on December 1, 1906, 26° C. seemed cool to the affected area on the forearm but produced no sensation of temperature over the back of the hand; but 23° C. was said to be cool over the forearm and intensely cold over the back of the hand. On August 7, 1904, 20° C. produced a cool sensation ("poor cold") only over the proximal part of the affected area on the forearm, "good cold" over the distal patch and "tremendous spot-cold" over the back of the hand.

At this time stimulation of the protopathic area in the neighbourhood of the wrist uniformly caused a sensation of cold, referred to the proximal patch on the forearm in the neighbourhood of the scar. By this means, a colder sensation could be produced than by applying the same tube directly to that part of the forearm. We are thus face to face with the following significant anomaly. A cold stimulus evoked a sensation of cold over a certain part of the forearm; but, when this stimulus was applied to a protopathic part on the hand, it produced a sensation referred to the same area of much greater coldness than that which followed direct application of an identical stimulus to the same part.

By carefully adapting the hand to cold, a condition can be produced in which 22° C. continues to cause a vivid sensation of cold from the protopathic area, but seems neutral to normal parts of the hand. An area of undoubtedly lowered sensibility then reacts with a specific sensation to a temperature, incapable under the circumstances of evoking a sensation from the normal skin.

An interesting example of failure to recognize this ambiguity with regard to intensity in the case of protopathic sensibility is given by von Frey's statement that the glans penis is the most sensitive part of the body to temperature. Now we have shown that this organ reacts to thermal stimuli like the skin in the protopathic stage after nerve division. It is a part of the body which is normally devoid of epicritic sensibility. A tube of 20° C. placed on the corona of the glans penis is said to be decidedly colder than on the adjoining skin; but tubes of 27° C. and 28° C., which produce obvious cold on the skin, evoke no such sensation from the glans. A region which has been called the most sensitive part of the body is as a matter of fact one of low sensibility, if tested by the customary measure of the threshold.

In the case of heat the results are the same; but, owing to the narrow range of temperature at our disposal, their demonstration is not so easy. Merely judged by the vividness of the response, a protopathic region would be called more sensitive than normal. A tube at 40° C. placed over a group of spots within the protopathic portion of the back of the hand seemed hotter than over normal parts; yet this area did not respond to any temperature below 37° C. When a silver tube containing water at 47° C. was rolled across the hand from normal to abnormal parts, it becams "hotter" over the affected area. But a tube at 35° C., obviously warm over the normal skin, no longer caused any sensation of warmth as soon as the protopathic border was passed. Judged by the standard of threshold, the protopathic area was less sensitive, although a temperature of 47° C. seemed hotter than over the normal hand.

At an early stage of recovery, the hairs regained a peculiar form of sensibility to contact. Stroking a hair-clad part with cotton wool produced a widespread tingling referred to parts at a distance, identical with those for the sensations evoked by painful and thermal stimuli. This tingling seemed to be more intense than the sensation which follows the brushing of normal hairs with cotton wool. But, when the roots of the hairs were tested by von Frey's method, not one of them was found to react to No. 5, although over normal parts the majority are sensitive even to stimulation with No. 3; and if the skin of the affected area was shaved, it became entirely insensitive to all cutaneous tactile stimuli.

Whatever the effective stimulus applied to an area in a condition of high protopathic sensibility, the specific sensation evoked will seem to be more vivid than that over normal parts. A prick will seem more unpleasant, cold will appear to be colder and brushing the hairs will cause a widespread tingling apparently more intense than any sensation produced by brushing the normal hair-clad skin.

Yet in every case the protopathic area is one of defective sensibility in spite of its more vivid response. Stimulation of the normal skin with a needle produces almost at once the sensation of a pointed object, which with increasing pressure passes gradually into pain. Thus, even if the threshold for painful stimuli may have sunk approximately to normal over protopathic parts, they still fail to respond to the antecedent sensation of a point. In the case of heat and cold, it can be shown that the threshold is always higher than over the normal skin. Even the tingling evoked by touching the hairs of a protopathic part, requires a stronger stimulus than when the skin is endowed with epicritic sensibility.

All forms of sensation evoked from protopathic areas have a high threshold, whether the condition be normal as in the case of the penis, or a stage in the recovery of sensibility after nerve division.

The most striking feature of the response from protopathic parts is its wide extensity. Each strictly local stimulation is followed, not by a localized sensation, but by an outburst of pain, heat, cold or tingling which may extend over the greater part of the affected area.

How large a part is played by this wide extent of the sensation, in our judgment of the relative coldness of a stimulus applied to protopathic parts, is shown by the following experiment. After the cold-spots had been marked out carefully, the protopathic area was stimulated with the flat circular bottom of a silver tube 1·25 cm. in diameter containing water at 20° C. This produced a sensation of cold. One active spot within the area covered by the tube was then stimulated with a copper rod 1 mm. in diameter which had been cooled to the temperature of ice. This caused a sensation, apparently "less intense" than that from the tube at 20° C., and the result was not altered by changing the order of the two stimuli. In these observations, H. was unable to recognize whether the smaller or the larger object was being applied; in one case when the tube had been used he said, "That is a good spot," comparing it with the previous stimulation with the rod only.

Increasing the area of stimulation produced the same effect as increasing the intensity of the stimulus. H. would have said that the tube at 20° C. was uniformly "colder" than the rod, had he not recognized that in many cases the coldness was not greater. Yet, although the resulting sensation was not more "icy," it was so much more extensive that his natural tendency was to call the tube a stimulus of greater intensity. This he might have corrected, had he been able to recognize that a larger area of skin was stimulated by the tube than by the rod; since this was impossible over a purely protopathic area, his only guide to the intensity of the stimulus was the extent of the sensation evoked.

But it must not be supposed that he was entirely unable to appreciate a difference in intensity between two stimuli of equal extent applied to a protopathic area. A tube containing ice will produce a colder sensation than the same tube containing water at 20° C. applied to the same parts. But, if once the stimulus is of a temperature low enough to excite the cold-spots to a full explosion of activity, the extent of the stimulus is of greater importance than its intensity.

In considering the direction in which the current notion of intensity might be revised, we must limit the application of the term in its strict sense to epicritic and to deep sensibility. In protopathic manifestations, there is undoubtedly a "more-or-lessness," which is of the same nature as that denoted by the term intensity, though it is liable to be obscured by variations in the extent of the stimulus.

It would even seem as if sometimes a less cold object applied to a larger surface will cause a sensation more intensely cold than the stimulation of a single spot by an iced rod.

Thus, even when we confine ourselves rigidly to the consideration of actual more-or-less coldness, a more extensive stimulus at a higher temperature may produce a definitely colder sensation, apart altogether from the fact that it radiates over a wider aaea.

From these facts, it follows that Weber's law or other expressions of exact quantitative relations between stimulus and sensation must undergo revision. In the case of the protopathic system, it is clear that there can be no question of any such exact relation. In the sensations from a protopathic area, there may exist a more-or-lessness which can be called intensity. But this is of so indefinite a character, and its relation to the intensity of the stimulus may be so obscured by differences in the extent of stimulation, that there can be no question of any such definite association between stimulus and sensation, as those formulated in Weber's law or Fechner's formula. As far as Weber's law holds good for the temperature-sense of the skin, we should expect it to be the expression of epicritic thermal sensibility. That is to say, it should be demonstrable, more particularly between 26° C. and 37° C., the highest point of the cold-spots and the lowest to which the heat-spots reacted. Further, the discriminative sensibility as revealed by the just-perceptible difference or the difference-threshold should be greater between these limits. It is remarkable that two of those who have investigated the validity of Weber's law for the temperature-sense have given figures corresponding closely with those to be expected on the basis of our view that the law holds true of epicritic sensibility only. Lindemann [20] found the discriminative sensibility to be greatest on the hand between the temperatures of 26° C. and 39° C.; the just-observable difference within these limits was 1·20° C. Nothnagel [24] found the most delicate discrimination between 27° C. and 33° C.; the just-perceptible difference was slightly larger only up to 39° C. and was also fair between 27° C. and 14° C. These observations help to support our view that, as far as the skin is concerned, Weber's law applies to epicritic sensibility only.

The results at which we have arrived in this chapter may be summed up as follows :—

(1) Parts in a condition of protopathic sensibility respond more vividly than the normal skin to all stimuli capable of evoking a sensation.

(2) This sensation is usually more intense and always of much greater extent than over normal parts.

(3) For all effective stimuli, the threshold is high in a protopathic area, and, in spite of the vivid response, it is obviously one of defective sensibility. Epicritic sensibility with its low threshold must be present before the sensory complex resembles that from the normal skin.

(4) An effective protopathic stimulus of low intensity, but covering a larger area, may produce a sensation of greater apparent intensity than a more restricted stimulation of greater strength. Not only is the sensation more extensive, but at times it may seem to be specifically more intense.

(5) The usual psychological view that an increased sensory reaction corresponds to a lowered threshold must be readjusted. It is true in the strict sense only of epicritic and deep sensibility.

CHAPTER X.—PUNCTATE SENSIBILITY.

Although our observations on the distribution and functions of the cold- and heat-spots agree substantially with those of previous observers, we differ from them fundamentally in our views of the nature of punctate sensibility. Blix ([4] and [5]) was the first who examined the skin minutely with stimuli of small extent, and discovered the heat- and cold-spots. He was followed by Donaldson [6] and later by von Frey ([7], [8], [9], [10], [11]) with a superb series of observations which greatly extended the original conception of punctate sensibility.

In consequence, it became a matter of general belief that the skin was endowed with sensitive spots, each of which reacted to a specific stimulus. Not only were there spots for cold and for heat, but also for pressure and for pain. To the activity of this mechanism were attributed all the sensory impulses arising from cutaneous stimulation.

But this minute concentration on the functions of the skin led to a neglect of those forms of sensation produced by the coarser stimuli, such as pressure. Any object, however light or heavy, was thought to be appreciated in consequence of impulses from the "pressure spots," so long as no movement of muscles or joints occurred. So soon, however, as the weight was supported by muscular effort, the " muscle-sense " came into action, based on afferent impulses conducted from the tendons, joints and other subcutaneous structures.

But division of all the nerves to the skin in our experiment showed that this deep innervation played a greater part in the sum of sensory impulses from the periphery than had been previously suspected. Much of what is commonly called "touch" is due to the activity of this afferent mechanism, and not to stimulation of the cutaneous " pressure-spots " only.

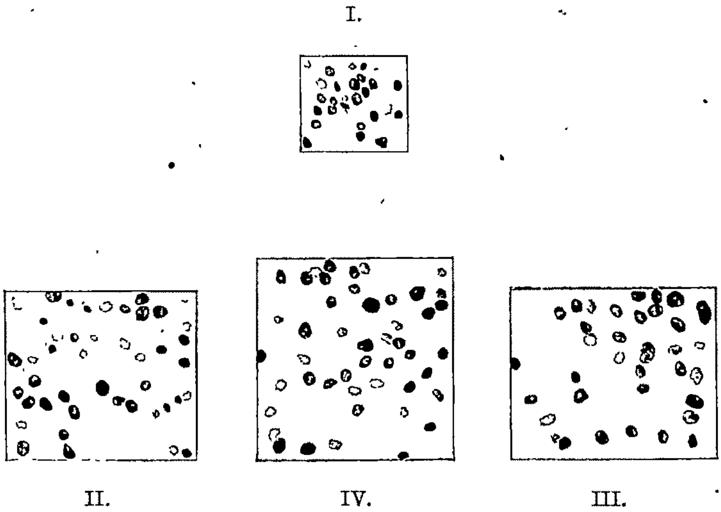


FIG. 23.

Photographed from Blix [4].

In the original the black dots are red and correspond to the heat-spots. The lighter dots are green and represent the cold-spots.

I.—An area on the dorsal aspect of the left hand at the base of the middle finger.
II —An area on the wrist.
III.—An area on the arm ("Armlange").
IV.—An area on the dorsal aspect of the left hand of another observer.

Excessive pressure was also found to produce pain when the cutaneous nerves were divided, and it is therefore certain that the "pain-spots" of the skin are not responsible for all painful sensations from the periphery. The pain of pressure and rending is due to the stimulation of end-organs of the deep afferent system.

It is therefore obvious that, of the sum of afferent impulses starting from the periphery, a large number arise from the activity of organs situated elsewhere than in the skin. On this side our observations are accessory to, but do not trench on, those of von Frey and his fellow workers. But even when we confined our attention to the skin, we found that the sensory spots did not account for all the afferent impulses of cutaneous origin which reached the central nervous system. It is therefore obligatory on us to show in how far we agree with, or differ from, the conclusions of previous observers with regard to punctate sensibility.

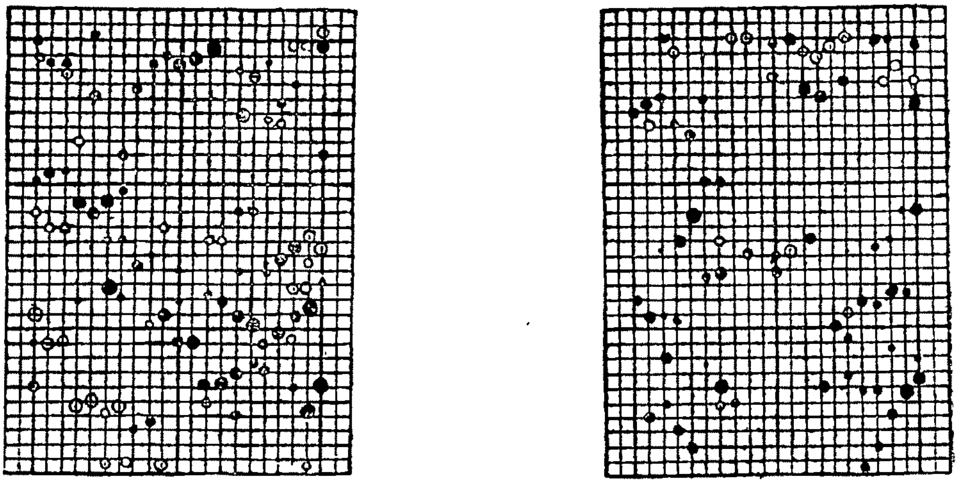


FIG. 24.

Somewhat enlarged from Donaldson [6].

The black dots indicate cold-spots. The larger ones represent the spots which gave a strong reaction, the smaller those which gave a weak one. Circles represent the heat-spots.

A. represents the distribution of the temperature-spots over six squares each of 1 cm. on the back of the left hand. B represents a similar map of a symmetrical part of the right hand. Thus each map is 2 cm. broad and 3 cm. in height.

The upper boundary is peripheral, the lower central; the left of the observer corresponds to the ulnar aspect, the right to the radial.

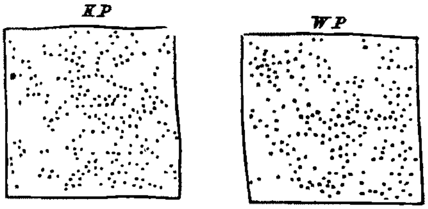
Section 1.—*Heat- and Cold-Spots.*

The existence of heat- and cold-spots has not been seriously called in question since they were first described by Blix [4]. They are easily demonstrable, scattered irregularly over the surface of the body (fig. 23). The cold-spots preponderate greatly; according to Blix there are from two to four cold-spots to one heat-spot. It is difficult to compare his results numerically with our own, because the size of the area chosen for investigation in different parts of the body evidently varied greatly, and he does not state whether his maps were drawn strictly to scale.

Donaldson [6] marked out six squares of 1 cm. on the dorsal surface of each hand; in these six squares he found on the right fifty-six cold-spots, and on the left fifty-nine. Within the same limits the heat-spots numbered seventeen and thirty-seven (fig. 24).

The area on the back of the affected hand most closely investigated by us consisted of twenty-five squares each of 1 cm. Here we found about sixty-eight cold-spots, and from fourteen to sixteen heat-spots. Some of these were more constant than others, and a certain number were discovered at every examination throughout the four years which followed their reappearance (*cf.* p. 377 and figs. 19 and 20).

Similar results were obtained by Sommer [26]; von Frey gives no maps of these spots, but from observations made by him on H.'s hand both before and after the operation, we can state that our results are numerically in complete accord with those obtained by his methods.



A. B.

FIG. 25.

Photographed from Goldscheider [15], Tafel 1.
In the original the cold-spots on A. are red, whilst the heat-spots on B. are blue.
Each area represents 4 cm. from the back of the hand.
It is obvious that both heat- and cold-spots vastly outnumber those recorded by other observers.

This remarkable harmony in the results of most observers is disturbed by the statements of Goldscheider [15] only. His maps reproduced in fig. 25 differ so greatly from the results of all other workers, that we can only assume he was not dealing with punctate sensibility as generally understood.

These spots respond to stimulation in a strictly specific manner. Thus, stimulation of the cold-spots with temperatures of 45° C. produces a sensation of cold. We have been unable to stimulate either the cold- or heat-spots with the interrupted current, provided all precautions are taken to exclude thermal stimuli and the effect of suggestion; in this we are at variance with Blix. We differ also from Goldscheider [15] in that we have been unable to evoke a sensation of heat or of cold by mechanical irritation of these spots, if the stimulating object be maintained at a neutral temperature.

Our observations have shown (chapter IV., section 3, p. 383) that the reaction of these spots is peculiar and characteristic. When sensibility to heat and cold depends on the existence of spots alone, any effective stimulus tends to produce a more vivid response than from the normal skin. Not only is the sensation evoked from a protopathic area of wider extent than normal, but at times it seems to be actually colder (*cf.* p. 422). Yet, in spite of this greater vividness, such parts as the affected area on the back of the hand and the normal penis did not respond to temperatures between 26° C. and 37° C. The degree of temperature necessary to stimulate individual spots varied greatly; but no heat- or cold-spot on the back of the affected hand responded to temperatures between these limits. This combination of an abnormally vivid response to effective stimuli, with failure to react to temperatures capable of exciting the normal skin, is a characteristic feature of all parts, where thermal sensibility depends on the existence of heat- and cold-spots only.

Moreover, so long as the thermal sensibility of a part depends entirely on these spots, it is incapable of that wide range of adaptation which is an inherent function of the normal skin (*cf.* p. 406). Soaking the hand in water at 45° C. does not cause the cold-spots to respond to temperatures above 26° C., and careful cooling does not increase the range of sensitiveness of the heat-spots. And yet, under such circumstances on the normal hand, adaptation would occur and the same intermediate temperature would appear at one time cool and at another warm.

It might be supposed that the vivid response, the high threshold and the want of adaptation so characteristic of punctate thermal sensibility on the affected parts were due to defective regeneration of the mechanism of the heat- and cold-spots. But the normal glans penis is unable to respond to temperatures between 26° C. and 37° C., not only when the stimulus is punctiform, but also when the whole organ is immersed in water. But so vivid are the sensations evoked by effective thermal stimuli, that von Frey calls it the most sensitive part of the body.

It is therefore certain that the cold- and heat-spots cannot account for all the thermal sensibility of the normal skin. Some other nervous mechanism must be present, which endows the skin with the power of reacting to intermediate degrees, and is capable of thermal adaptation.

But when all the cold- and heat-spots have been marked out on the normal skin, considerable spaces remain between insensitive to punctate thermal stimuli. These, if sufficiently extensive to be tested with a tube, will be found to be sensitive to water above 26° C. and below 37° C., especially after the part has been suitably adapted.

We therefore believe that the skin is endowed with two thermal mechanisms, one of which reacts to punctate stimuli and has a high threshold judged by the inability to respond to temperatures between 26° C. and 37° C. Its end-organs are strictly specific and are dotted about irregularly throughout the skin, in such a way that large spaces may be entirely devoid of heat-spots.

The second mechanism is incapable of reacting to punctate stimulation, but responds readily to temperatures above 26° C. and below 37° C., when applied over an area of some extent. The nature of this response depends on the temperature to which the part is adapted. At one moment 30° C. may seem warm, at another cold according to whether the skin has been previously adapted to cold or to heat respectively.

Section 2.—Pain-Spots.

Blix [5] denied that sensibility to pain was associated with any mechanism analogous to the heat- and cold-spots. But in consequence of the widely extended observations of von Frey on various forms of punctate sensibility, the idea has gradually grown up that pain-spots exist in the skin in every way comparable to, but more numerous than, the cold- and heat-spots. Thus Thunberg ([28], p. 651) says: "Erst v. Frey fand dass die Verhältnisse hier (for pain) ganz analog denjenigen der anderen Sinnespunkte liegen."

But no observations by von Frey bear such an interpretation. His great contribution to the subject of skin-sensibility was the introduction of measurable mechanical stimuli, not only for touch but for pain. He selected a large number of hairs of different sectional area and bending strain, and showed that as soon as a certain pressure per unit area was exceeded, pain was produced. This threshold for pain of cutaneous origin differed greatly in various parts of the body. If a test-hair was chosen which just exceeded this amount, it formed a minimal pain-stimulus for that particular part of the body. Such a hair will be found to cause the characteristic pricking sensation at a few points only. These are von Frey's "pain-spots" (Schmerzpunkte). But by increasing the strength of the stimuli, *i.e.*, by using hairs of greater bending strain, many more points can be discovered from which pain can be evoked; at last, the number of such points within any square centimetre becomes so great that it is scarcely possible to map them with accuracy.

Suppose, however, that one or more square centimetres has been examined exhaustively and that these minimal pain-spots have been marked on the skin. On subsequent examination, even an hour or two later, it will be found that many of the spots no longer respond to the same stimulus; for instance, those which had previously reacted to 75 grm./mm.^{2} may be insensitive to hairs of less than 150 to 200 grm./mm.^{2}. Moreover, many unmarked places will be found to respond even to hairs which exert a comparatively low pressure per unit area. Whatever ultimate view we may take of the nature of pain-spots, experimental observations on their distribution are much less conclusive than those on the heat- and cold-spots.

The true nature of cutaneous painful sensibility cannot be settled by examination of the normal skin. But the answer is given at once when we turn to the permanently protopathic area on the back of H.'s hand. Here the skin responds to temperatures below 26° C. and above 37° C. only, and painless stimulation of the hairs produces the characteristic diffuse sensation; pain extending widely, and referred to remote parts, can be evoked by stimulation with the stiffer test-hairs. Such an area is usually supposed to be in a low state of sensibility. But on testing with graded hairs, the threshold for pain is found to be the same as that for the normal skin. Sometimes, owing to the greater technical ease of the observations, this protopathic area gave a painful response to hairs of a lower grade than was the case over an equivalent part of the normal skin. Far from being a region of defective painful sensibility, the threshold for cutaneous pain was here as low (1908), and possibly even lower than normal. This we can affirm, not only from our own observations, but from a careful examination made by Professor von Frey of that part of H.'s hand.

But, although fully sensitive to pain, this area is entirely insensitive to the tactile test-hairs. Pain, instead of developing gradually out of the sensation of contact with a pointed object, arises without warning as soon as the force exerted by the "pain-hair" exceeds the threshold for the particular spot to which it is applied.

Within this protopathic area, in spite of the simpler condition, we find exactly the same inconstancy of reaction to cutaneous painful stimuli as in the normal skin. By using hairs which just exceed the pain-threshold, two or three spots can be marked out in each centimetre; these are the minimal pain-spots of von Frey. Even these are inconstant in reaction, and by using hairs of greater bending strain, a multitude of further spots can be discovered within each square.

Thus it would seem, that the pain-spots within any square centimetre are extremely numerous and possess widely different thresholds. Moreover, they are inconstant, varying in sensitiveness from time to time.

This variability and inconstancy of reaction they share with the heat- and cold-spots. Within the twenty-five squares on the back of H.'s hand, lay sixteen points where at one time or another heat was evoked by punctate stimulation; of these, thirteen were marked out as the site of heat-spots on ten or more of the eighteen photographic records, that is to say three heat-spots were so inconstant that they were frequently missed.

But even amongst those spots which could be discovered without difficulty, the threshold was by no means the same. Two of them usually reacted to 38° C., but a large proportion did not respond to temperatures below 40° C.; in order to be certain that every spot had been fully tested, we always employed an iron at about 45° C.

When we examine the records of the more numerous cold-spots, the proportion of inconstant ones greatly increases. In fact, the photographs are so diverse that we have been compelled to confine our attention to those which are accompanied by an explanatory key recording the constancy of response. Among the sixty-eight spots, thirteen only are present in all three sets of maps and photographs.

The small number of the heat-spots and the complete absence of sensibility to heat in the intervening spaces of the protopathic skin make it easy to settle their number and to record their position. This is more difficult with the cold-spots and, with the further increase in number shown by the pain-spots, becomes an impossibility. Moreover, it is easy to be certain that no active cold-spots have escaped, by using a rod at the temperature of melting ice. But, with the pain-spots, a great increase in the strength of the stimulus leads to such deformation of the skin that the stimulus no longer acts in a punctiform manner.

But in spite of the technical difficulties in mapping out the pain-spots, they are evidently closely allied in origin and function to those for heat and cold. After division of a peripheral nerve, the three sets of organs recover their functions approximately together, and a part may remain for a long period sensitive to painful and to the more extreme degrees of thermal stimulation only. Sometimes, regeneration may stop short at this protopathic stage, and the hairless skin will then be sensitive exclusively to stimuli capable of exciting the pain-, heat- and cold-spots. This is not due to defective restoration of the nerve-mechanism of the spots themselves, for the cutaneous sensibility of the glans penis depends entirely on the activity of these spots; it is a part of the skin which has remained normally in a protopathic condition.

Moreover, so long as the skin is innervated through these spots only, the sensation is widely diffused, and referred into some remote part which is constant whatever stimulus be applied, provided the area stimulated is the same.

Thus, it is obvious that the cutaneous mechanism which underlies painful sensibility belongs to the same order as the heat- and cold-spots, both in the period at which it regenerates and in the nature of its response to stimulation.

The heat- and cold-spots form a thermal mechanism with a high sensory threshold, incapable of responding to temperatures between 26° C. and 37° C. But a cutaneous painful sensation can be evoked from a highly developed protopathic part as easily, and in some cases even more easily, than from the normal skin. It would seem at first sight as if protopathic sensibility was not in this case associated with a high threshold.

But careful analysis of the effect produced by stimulation with graduated hairs shows that, although pain is produced as easily over highly protopathic parts as over the normal skin, the complex of sensations is different. When a hair of between 70 and 100 grm./mm.^{2} is applied to the protopathic area, a sensation of localized pressure is produced, followed by the gradual development of the characteristic stinging pain. Over the normal skin, the first sensation, when the hair is applied, is one of a circumscribed pointed object; to this, a definite painful element is gradually added. At pressures incapable of producing pain, the sensation of a point warns the patient that the stimulus, if increased in strength, may become painful. This recognition of the pointed nature of the stimulus is due to the power of appreciating relative size, a faculty which depends on impulses arising in the epicritic mechanism.

Pain is always a high threshold sensation as shown by the fact that it is not evoked by punctiform stimuli until the pressure exceeds 70 grm./mm.^{2}. The low threshold contribution to the sensory complex, introduced by the existence of epicritic sensibility, consists in the power of recognizing that the stimulus is pointed, before the pressure is sufficient to cause pain.

In conclusion, we believe that the sensibility of the skin to painful stimulation depends upon organs analogous to the heat- and cold-spots; and just as the latter are more numerous than the former, so the pain-spots exceed the cold-spots in number. With this excess is associated a wide diversity of threshold and a greater inconstancy of response, so that it is experimentally impossible to mark out with certainty all the pain-spots in a given area. Von Frey's pain-spots comprise those of the lowest threshold only, which react to the minimal punctate pain-stimulus for any particular area of the skin.

The pain-spots resemble those for heat and cold in that the threshold of even the most sensitive is remarkably high. Stimulation of the skin with graduated hairs produces a widely diffused sensation of pain, with no antecedent appreciation of the pointed nature of the stimulus. This faculty first returns with the restoration of the low threshold impulses of the epicritic system.

Section 3.—Touch-Spots.

So far we have considered the reaction to punctate stimuli of three sets of end-organs, which recover their function early within approximately the same period after nerve division. A portion of the skin, innervated by these organs only, shows sensory peculiarities which we have called protopathic and is entirely insensitive to cutaneous tactile stimuli, provided the hairs are not disturbed.

But it is universally recognized that on the normal skin, punctate stimuli produce a sensation of touch. Blix described what he called "Druckpunkte," points in the skin peculiarly sensitive to touch, in close relation to the roots of the hairs. These observations were amplified by von Frey, who found that these "Druckpunkte" possessed a remarkably low threshold. He was, however, unaware of the phenomena of deep sensibility and did not recognize that comparatively slight pressure could produce a localized sensation, although the skin was entirely insensitive. This name is therefore unfortunate, and we shall speak of "touch-spots," whenever we allude to these sensitive cutaneous points ("Druckpunkte").

These spots belong to a different order from those for pain, heat and cold. They regain their function at a much later period of regeneration, if the nerve has been completely divided. Thus the proximal patch on H.'s forearm became sensitive to prick 56 days after the operation; sensibility to cold returned in 112 days, and in 161 days this part responded to heat. But it was not until 366 days after the operation, that the same area when shaved became sensitive to cutaneous tactile stimuli.

Should any part of the skin happen to remain permanently in a protopathic condition, it will show all the properties of punctate sensibility to pain, to heat and to cold, but will be devoid of touch-spots. This is the normal condition of the glans penis.

Conversely, the skin of the "triangle" was sensitive to cutaneous tactile stimuli and was endowed with touch-spots resembling in function those of the normal skin. But no pain-, heat- or cold-spots could be found anywhere within this area.

We have already described the close association between the returning response to cutaneous tactile stimuli and the recovery of sensibility to intermediate degrees of temperature, more particularly to warmth. Thus, a part such as the back of the hand may remain for a long while innervated by pain-, heat- and cold-spots only, insensitive to temperatures between 26° C. and 37° C. and to painless stimulation with von Frey's test-hairs. As soon, however, as the touch-spots reappear, the part will be found to have regained in addition its sensibility to intermediate degrees of temperature.

Moreover, the return of function to the touch-spots is closely associated with recovery of the power of accurately localizing cutaneous tactile stimuli. Before this group of sensory functions has reappeared, discrimination of two points applied simultaneously is impossible. But with the recovery of sensibility to von Frey's tactile hairs, accurate localization and discrimination become possible. The wide radiation and reference into remote parts, so characteristic of the unchecked activity of heat-, cold- and pain-spots, ceases and is replaced by a less vivid sensation, restricted to the immediate neighbourhood of the point of contact. Thus, the return of function to that sensory mechanism of which the touch-spots form a component, actually diminishes the sensations associated with the activity of those organs, which are universally accepted as the type of cutaneous sensory spots.

Over hair-clad parts, these touch-spots are strictly associated with the roots of the hairs; they express the sensibility to mechanical stimuli of that part of the hair which lies beneath the surface of the skin. Almost every hair is a delicate tactile sense-organ; any movement of its tip is transmitted to its root with the increased power of a lever, setting up tactile impulses. It is not remarkable, therefore, that mechanical stimulation, applied directly to the hair-root, produces similar tactile sensations. But owing to the want of leverage, this method of stimulation is less effective, and the force required to produce a sensation is higher than when the free portion of the hair is disturbed.

Even when care is taken to touch no part of a hair lying above the skin, the threshold for punctate tactile sensibility is extremely low. Out of 303 touch-spots on von Frey's forearm, 221 reacted to a force of or below 1 grm./mm. (8 grm./mm.^{2}); sixty-six required 2 grm./mm. (12 grm./mm^2), and there was not one which did not respond to 4 grm./mm. (21 grm./mm.^{2}). Such threshold values are roughly one-fourth of those required over the same parts to produce a painful sensation.

But it must not be supposed that these touch-spots are the same as those for pain. The majority of the pain-spots lie between hairs, whilst on hair-clad parts touch-spots correspond almost exclusively to hair-roots. It must not be forgotten that a hair-root may be found to be the seat of both a touch- and pain-spot owing to the sensibility of many of the hairs, both to tactile and to painful stimuli. But, whereas the spaces between the hairs contain many pain-spots, touch-spots are almost entirely absent. Von Frey discovered three touch-spots only which were not definitely associated with the hair-roots, in a space of seven 1 cm. squares on the calf of the leg. Within the same area he marked out seventy-seven touch-spots connected with the hairs ([11], p. 233).

Almost all the observations on touch-spots have been made on hair-clad parts of the skin; here, as von Frey has shown, they correspond to the subcutaneous portions of a hair. But the tips of the fingers are even more sensitive to the test-hairs than any hair-clad part. Thus the finger responds to 3 grm./mm.^{2}, but the back of the hand requires 12 grm./mm.^{2}. Here the existence of definite touch-spots cannot be demonstrated with certainty, so numerous are the points sensitive to stimulation with test-hairs.

We have shown that when any part of the skin, whether endowed with hairs or not, becomes sensitive to punctate tactile stimuli, it shortly regains its sensibility to temperatures between 26° C. and 37° C. Yet the heat-spots are not increased in number and do not react to thermal stimuli below 37° C. This return of function must be due to some mechanism of a different order from the heat-spots.

In the same way, we believe that the return of cutaneous tactile sensibility is coincident with the restoration of function to a set of end-organs of a different order from the heat- and cold-spots. On hairless parts of the skin, such as the finger-tips, they are so thickly scattered that it is impossible to demonstrate their punctate distribution. But over hair-clad parts they are associated peculiarly with the hairs, and every hair-root therefore becomes a sensory spot.

The conclusions arrived at in this chapter can be summed up as follows:—

(1) The skin is supplied by two anatomically distinct systems which have been called protopathic and epicritic, and regenerate at different periods after complete nerve division. Moreover, a part of the skin may be supplied by one of these systems only. Thus, the cutaneous sensibility of the normal glans penis is protopathic, closely resembling the present condition of a small portion of the affected area on the back of H.'s hand. Conversely, the "triangle" was sensitive to tactile test-hairs and to warmth, but was completely devoid of heat-, cold- and pain-spots.

(2) Protopathic sensibility depends upon specific end-organs gathered together within the skin to form sensory spots; the spaces between are insensitive to cutaneous stimuli, if the part is endowed with protopathic sensibility only.

Owing to the sparseness of the heat-spots, their characteristics can be easily demonstrated; cold-spots are more numerous and correspondingly difficult to investigate. The pain-spots are so closely distributed throughout the skin that it is impossible to study them with the accuracy of the heat- and cold-spots; but the character of their response, and the period at which they regenerate, show that they belong to the same order.

(3) Whenever the skin is supplied by protopathic end-organs only, any sensation evoked radiates widely and tends to be referred to remote parts. These are the same, whichever kind of spot be stimulated, so long as it lies within the same area of the skin.

Radiation and reference are abolished, as soon as the part becomes sensitive to cutaneous tactile stimuli and to intermediate degrees of temperature.

(4) Any part of the skin, innervated by heat- and cold-spots only, is incapable of that wide adaptation to external temperatures so characteristic a function of the normal skin.

(5) Cutaneous tactile sensibility is due to the activity of a sensory mechanism of a different order from the heat-, cold-, and pain-spots. It regenerates much later after complete nerve-division. The restoration of cutaneous tactile sensibility is closely associated with the return of the capacity to appreciate temperatures between 26° C. and 37° C., with the

power of accurate cutaneous localization and with the discrimination of two points.

Its end-organs become susceptible of investigation with punctate stimuli over hair-clad parts, owing to their close association with the roots of the hairs. But these "touch-spots" (Druckpunkte of Blix and von Frey) are not analogous to those for heat, cold, and pain.

(6) All protopathic sense-organs have a high threshold; the heat-spots do not react to temperatures below 37° C., the cold-spots do not respond to temperatures above 26° C. and the pain-spots on the back of the hand are insensitive to pressures below about 70 grm./mm.^{2}.

All epicritic sense-organs have a low threshold. They respond to temperatures between 26° C. and 38° C., and the back of the hand is sensitive to 12 grm./mm.^{2}.

A protopathic part, whether it be the normal glans penis, or the affected part of H.'s left hand, is in a condition of high threshold sensibility. When the normal skin is stimulated, the defects of protopathic sensibility are corrected and compensated by the simultaneous activity of the low-threshold epicritic system. Temperatures between 26° C. and 37° C. can produce sensory impulses, and the epicritic mechanism is highly adaptable. The threshold for painful sensations is the same over normal and over highly protopathic parts, but on the normal skin the approach of pain is preceded by the sensation of contact with a pointed object. This is absent over protopathic parts. The power of recognizing the pointed nature of the stimulating object depends on the existence of epicritic sensibility, and belongs to that group of sensations by which we estimate relative size.

CHAPTER XI.—GENERAL THEORETICAL CONCLUSIONS.

Section 1.—*The Integration of Afferent Impulses.*

Throughout this paper we have spoken of three forms of sensibility, and in the previous chapter we gave our reasons for the belief, that they were associated with the activity of three anatomically distinct systems.

Johannes Müller believed that on stimulating the body-wall a specific impulse was initiated, which passed unaltered to the brain, forming the basis of a specific sensation. In the same way Blix [4], when he discovered the heat- and cold-spots, thought that the impulses arising in these specific organs passed unchanged through the nervous system to underlie all sensations of heat and cold.

But we have been able to show that the process is one of much greater complexity. Under normal conditions there are no "protopathic" or "epicritic sensations." These terms may be justly applied to two anatomically distinct peripheral systems, or to the sensibility with which the skin becomes endowed by the preponderating activity of one or other nervous mechanism. They can also be used to distinguish two groups of impulses set free by stimulation of the end-organs in the skin. But sensations must be described solely by their specific qualities, and not by these names which apply to the peripheral physiological level only.

For, as soon as they reach the first junction in the central nervous system, sensory impulses are transformed into more directly specific groups. Both protopathic and epicritic end-organs may be stimulated by heat applied to the skin and the resulting impulses will travel by separate peripheral paths to the spinal cord. There they become united and pass on, as a single isolated group, to underlie, in the highest centres, specific sensations of heat.

A similar fusion of originally separable elements occurs when the skin is stimulated with cold, and the intramedullary path transmits an equally specific group of impulses.

In the same way, the physiological basis of a sensation of pain may be compounded of elements due to stimulation of the end-organs of the skin and of the deep afferent system. These, when united, pass up together in the same isolated paths devoted to the transmission of sensory impulses evoked by painful stimuli.

Epicritic tactile impulses become combined with those arriving by way of the deep afferent system into a single tactile group. Once past the first synaptic junction, epicritic impulses, evoked by the lightest perceptible touches, become simply the minimal physiological elements in a tactile group, of which the maximal constituents, produced by pressure, arrive by way of the deep afferent system.

But pressure acting on the end-organs of this deep system may cause sensations of pain in addition to those of touch. Under such circumstances, the tactile impulses evoked by pressure will arrive at the spinal cord in company with those which underlie pain. On reaching the first synaptic junction, these two elements become separated. The tactile impulses are combined with those arriving by way of the epicritic system; whilst those associated with the painful aspect of pressure pass into a secondary path, in conjunction with impulses arising from stimulation of the pain-spots in the skin. When once the secondary afferent system has been reached, no traces remain of the original grouping in the peripheral path (Head and Thompson [18]).

This integration takes place on a physiological level; the whole process remains entirely outside consciousness. Throughout their passage from the periphery to the highest centres, these impulses undergo redistribution from the complex elementary grouping to something simple and specific.

The process, so far as we have yet considered it, has been one of sorting only. Impulses, originated by similar aspects of the same stimulus, have been gathered together, although they arose in end-organs of different systems. When, however, we consider that a temperature of 45° C., applied to the normal skin, can be shown to stimulate the heat-spots, the cold-spots and the epicritic thermal mechanism, it is obvious that some of these peripheral impulses must be inhibited; they never reach the highest centres to form the basis of a sensation. It might be objected that under normal circumstances the cold-spots are not stimulated by a temperature of 45° C.; but, provided the heat is applied directly to a cold-spot, paradox-cold is easily evoked from the normal skin. As soon, however, as a heat-spot is stimulated at the same time, the cold sensation disappears, giving place to one of heat. Evidently, the impulses produced by the action of 45° C. on the heat-spots and epicritic thermal mechanism are dominant to those evoked from the cold-spots. During the protopathic stage of recovery, it was possible to find parts where the thermal mechanism consisted of cold-spots only. Here even tubes containing water at 45° C. caused a sensation of cold.

The behaviour of the penis forms an excellent example of such inhibition. In the case of H., the tip happens to be devoid of heat-spots but is sensitive to cold and to pain. When, therefore, it was dipped into water at 40° C., no sensation of heat was produced, but H. experienced an unusually disagreeable sensation of pain. When the water was raised to 45° C., this was to a great extent displaced by a vivid sensation of cold. But, as soon as the water covered the corona without reaching the foreskin, both cold and pain disappeared, giving place to an exquisitely pleasant sensation of heat. The corona is richly endowed with all forms of protopathic sensibility; but the impulses, which must have been evoked from the end-organs for pain and for cold by contact with the water at 45° C., were inhibited by those consequent on stimulation of the heat-spots. Moreover, we can estimate the relative dominance of the impulses evoked by any particular temperature. At

45° C., those which form the basis of sensations of pain are controlled by those evoked from stimulation of the cold-spots, and both recede before the impulses which underlie a sensation of heat. But a further rise in the temperature of the stimulus to about 50° C. causes a sensation of pain together with one of heat, and the only inhibited impulses are those from the cold-spots.

The following experiment on H.'s hand shows this inhibition in a still more remarkable manner. A portion of the affected area in the neighbourhood of the index knuckle remains in a purely protopathic condition, and adequate stimulation of the skin still causes a vivid sensation of cold referred to the dorsal aspect of the thumb. If this part of the thumb was brought into contact with a large vessel containing water at between 40° C. and 44° C., H. experienced a pleasurable sensation of heat. A cold tube was then applied to the neighbourhood of the index knuckle, and the impulses which would normally have evoked a sensation of cold in the thumb were neutralized by contact of this part of the skin with the warm vessel. All sensations of heat at once disappeared from this portion of the thumb, and gave way to a new sensation, that of pain. As we know from experiments on the penis, temperatures of from 40° C. to 44° C. can evoke pain in the absence of the thermal mechanism. Evidently, therefore, the warm vessel stimulated the pain-spots in the thumb, but the impulses so caused were inhibited by those which underlay the sensation of heat. When these impulses were neutralized by the application of cold to the region of the index knuckle, those evoked from the pain-spots were no longer blocked, but passed onwards to form the basis of a painful sensation.

Throughout the first or protopathic stage of recovery in our experiment, the vividness and extent of the reaction became greater with the gradual return of sensibility to pain and the increasing number of heat- and cold-spots. This tendency to evoke a sensation, in parts remote from the point of stimulation, was curtailed or even abolished, at the height of its development, with the first signs of returning sensibility to cutaneous touch and to minor degrees of heat. Had the recovery of sensation taken place by gradual increments, we should have expected the steady increase in protopathic sensibility to be associated with a simultaneous decrease in radiation and reference. But in no part of the affected area was this form of sensibility so high and reference so vivid as in the patch on the back of the hand, which still shows no signs of epicritic recovery (autumn of 1908). The return of epicritic impulses diminishes protopathic activity, as expressed in the sensations evoked by stimulation of the end-organs of this system.

This is proved by the behaviour of the recovering hand after it had been cooled. Epicritic sensibility is liable to be affected by external cold, especially before it has been completely restored. At a time when almost the whole of the back of H.'s hand had so far recovered that referred sensations could no longer be produced, it was rapidly cooled; it thereupon ceased to respond to cotton wool when shaved. Radiation and reference returned as vividly as of old, and the hand was thrown back into a purely protopathic condition. The newly recovered activity of the delicate epicritic mechanism was disturbed by the cold, and protopathic impulses previously inhibited now passed through uncontrolled.

This control[1] can be exerted even by epicritic impulses from the adjacent normal skin. If a cold tube was placed so that it fell wholly within that part of the affected hand which remains in a protopathic condition, a vivid referred sensation was always experienced in the thumb. But when the base of the tube fell partly within the abnormal area and partly on the neighbouring skin, reference was abolished; the only sensation produced was one of coldness around the spot on the back of the hand in contact with the tube (*vide* p. 420).

The first stage of recovery after complete division of all the peripheral nerves to any part of the skin is occupied in the restoration of protopathic sensibility. Throughout this period, protopathic impulses are not inhibited; owing to the absence of the epicritic system and the sensations of pain, heat and cold are not only more vivid, but are referred into remote parts. But none of these phenomena accompanied the return of sensibility to the heat-, cold- and pain-spots within the "triangle." This area on the back of the wrist was from the first sensitive to cutaneous tactile stimuli, and two points applied simultaneously within it could be discriminated; but we were unable to discover any signs of punctate sensibility to pain, heat or cold. Gradually these spots reappeared; but the sensations evoked when they were stimulated were no more vivid or extensive than normal. The existence of epicritic sensibility throughout the period of protopathic regeneration controlled the aberrant manifestations of this system.

Section 2.—Sensory and Non-sensory Afferent Impulses.

Some afferent impulses never reach consciousness at all, but carry out their functions reflexly on the physiological level. To this group belong those which influence muscular tone, and control the condition of the vessels.

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[1] This control can be explained by the hypothesis of drainage put forward by McDougall [28]. We hope to deal with this question and with dominant activity of low-threshold sensibility in a subsequent paper.

But many impulses capable of forming the basis of a sensation are prevented under normal conditions from reaching the highest centres; or if their forward path is not completely barred, they pass on in a profoundly modified form, in consequence of the concurrent activity of other sensory end-organs. The utility of this arrangement is obvious, especially in the case of those impulses which underlie sensations of pain. Temperatures of from 40° C. to 45° C. normally cause a pleasurable sensation of heat, although, in the absence of the heat-spots and epicritic thermal mechanism, pain is produced. Such temperatures are adequate stimuli to the pain-spots, at any rate on the back of the hand, but the impulses evoked are prevented from reaching the highest centres by the effects of coincident stimulation of the thermal end-organs. As the temperature rises, these potentially painful impulses increase in strength, until they can no longer be inhibited; they then form the basis of a sensation of pain. In this case, consciousness is not disturbed, until impulses are produced, not only in themselves of adequate strength to evoke a sensation, but able to overcome the inhibitory effect of the activity of other specific end-organs.

In a similar way, the return of epicritic sensibility reduces the amount of pain caused by cutaneous stimuli, without at the same time raising the threshold. Radiation and reference are inhibited, and the pain produced by a prick is restricted to the immediate neighbourhood of the spot stimulated. This diminution in extent reduces the amount of pain suffered by the patient, although the measured threshold for painful sensations may be actually lower than during the preceding protopathic stage.

So long as a part of the body is innervated by the end-organs of the deep and protopathic systems, two incompatible forms of localization are possible. Painless pressure will be localized in the neighbourhood of the spot to which it is applied; but the sensation evoked by purely cutaneous stimuli will radiate widely, and be referred into some remote part. Both forms of localization may be present in consciousness together. When a cold test-tube is applied to the permanently protopathic area on the back of H.'s hand, the pressure of the tube is localized in the neighbourhood of the point of contact, but the cold sensation is said to lie mainly in the thumb. Thus, the existence of comparatively accurate tactile localization, due to the deep afferent system, does not seem to inhibit or control the impulses produced by stimulation of protopathic end-organs. But, when once a part of the body is endowed with epicritic sensibility, reference ceases entirely.

It has been suggested (von Frey [14]) that protopathic sensibility is due to anatomical changes which have taken place within the central nervous system, in consequence of the abnormal state of the injured nerve. On the other hand, we believe that this condition is due to the uncontrolled passage of a set of impulses, which normally undergo modification or inhibition before they reach the highest centres. This view is supported by the existence of a normal protopathic surface, such as that of the glans penis.

Most of the characteristic reactions obtained from a part in a condition of protopathic sensibility undergo modification with the return of epicritic impulses; reference alone is completely abolished. It may be asked why a function apparently so useless remains, though in a condition of permanent suppression. The answer to this question is given by the existence of referred pain in disease of the internal organs. These parts are probably innervated, like the glans penis, from the deep and protopathic systems. But, unlike the glans, their sensibility is extremely low; heat- and cold-spots must be scanty or even absent from most parts of the stomach and intestines. Moreover, pain cannot be produced by such stimuli as the prick of a pin, adequate to evoke sensations from protopathic parts on the surface of the body. Internal surfaces cannot respond to artificial stimuli, to which they have never been exposed during the life of the individual or the race.

Even if a stimulus is adequate to evoke impulses from these sheltered parts of defective sensibility, it does not usually produce a sensation, in consequence of the concurrent activity of the sensory organs of the skin. But a sensation may be produced, whenever these visceral impulses become sufficiently strong to overcome this inhibition, or when the central resistance to their passage is in any way lessened. Once the path has been opened, the resistance to potentially painful impulses is lowered, and a weaker visceral stimulus will evoke a sensation. To this diminished resistance is probably due the production of pain by otherwise inadequate stimuli in cases of long-continued visceral irritation.

Since the internal organs are totally devoid of epicritic sensibility, a sensation produced within the visceral area will tend to show the same peculiarities as one evoked from a part supplied with deep and protopathic sensibility only. If the stimulus consists of pressure or of the movement of muscles, the patient will recognize to some extent its true locality, in proportion as the part is supplied with end-organs from the deep afferent system. When, however, the stimulus evokes pain the sensation will tend to be referred into remote parts.

Now, just as one part of the affected area on H.'s hand seemed to be linked with some other remote portion, so visceral sensory surfaces seem to be closely associated with somatic segmental areas. When pain is evoked, it is not localized in the organ stimulated, but is referred to some area on the surface of the body.

Thus, the retention, on the primary level, of afferent impulses, which, if not inhibited, would lead to incorrect localization, has a protective object. To the normal organism they would be worse than useless, but in disease they underlie widespread pain and uncontrollable muscular reflexes.

The sensory processes discussed in this chapter take place on the physiological level. Psychological analysis fails entirely to disclose the struggle of sensory impulses revealed by our experiment. Integration occurs as impulses pass from the periphery towards the higher centres; the change is a constant one from a complex to a simpler and more specific grouping. Sensation, the final end of the process, assumes forms simpler than any sensory impulses.

We believe that the essential elements exposed by our analysis owe their origin to the developmental history of the nervous system. They reveal the means by which an imperfect organism has struggled towards improved functions and psychical unity.

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AN EXPERIMENTAL STUDY OF THE OCULAR REACTIONS OF THE INSANE FROM PHOTOGRAPHIC RECORDS.

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WITHIN the last few years exact knowledge of the normal movements of the eyes has made rapid advance, particularly in America, through the use of mechanical and photographic registering devices. Quantitative information is now at hand with respect to the angle-velocity [2, 3, 9][1] and the path of the line of regard during rapid eye-movements [4-6, 8, 10-16],[1] the accuracy, stability and variability of fixation under a considerable variety of circumstances [4, 6, 8, 10-15],[1] the ocular reaction-time [8],[1] and the peculiar modifications of eye-movements which constitute short-lived motor habits [5],[1] pursuit movements [7],[1] co-ordinate compensatory eye-movements [7, 8],[1] and the movements of convergence [12].[1]

The ease with which the photographic technique can be adapted to a wide variety of experimental requirements, together with certain peculiarities of the eye-movements themselves, led the writers to believe that a comparative study of the eye-movements of normal and insane persons might be made a fruitful contribution to our experimental knowledge of the reactions of the insane.

Such a comparative study might well find its basis in any of a large variety of experimental data. The present investigation was limited to three main problems, which were relatively clear to us, and to meet which we framed our technique.

The difficulties in any experimental study of normal psycho-physical processes are serious enough, even though one may rely on the highest degree of intelligent coöperation on the part of the subject. In the study of abnormal mental life, additional difficulties arise from the very nature of the object of investigation, in direct proportion to its variation from the normal. As Kraepelin cogently observes, lack of comprehension of the experimental test, lack of ability to execute it, lack of interest, coöperation, and of endurance, all conspire to increase the task of the experimenter and to modify the value of his results. The consequent demand for trustworthy experimental methods, which, without too complicated technique or too unusual demands on the patient, shall yield quantitative information of significant variations from normal reactions, voices at once the need and the embarrassment of experimental psychiatry. These demands are met in part at least by the reactions of the eyes as they are known through their photographic records.

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[1] Numbers 1 to 16 refer to the bibliography at the end of the paper (pp. 488, 489).

Eye-movements are neither unusual nor difficult. On the contrary, the ability to look at a bright object which appears suddenly within the field of view is one of the earliest forms of motor organization to be achieved, and it is retained long after the ability to learn new and complex forms of reaction is irretrievably lost. A patient will naturally look at a suddenly appearing object when he could learn the simplest new reaction only imperfectly and with enormous waste of time.

Moreover, while the eye-movements are intimately associated with the most complex mental activities, they are peculiarly inaccessible to subjective observation. Even the best trained observers utterly failed by introspection to discover some of the facts of eye-movements which are most conspicuous in the photographic records. For the ordinary man, his eye-movements are usually involuntary and unconscious; they are essentially a part of the mechanical preadjustments of vision, and consciousness is concerned with the result rather than the preadjustments. They may on occasion be consciously initiated, but once begun they are entirely withdrawn from conscious control. This effectually prevents both arbitrary modifications and successful simulation of pathological symptoms. Moreover, relative uniformity in the previous training gives unequalled opportunity for legitimate comparison between different persons. Probably no other form of reaction is common to so many different persons in so high a state of development. The nearest competitor in this respect are the various speech functions; but gross differences of individual habits and training render generalization concerning the latter more difficult. In the eye-movements, on the other hand, we may reasonably assume almost complete identity of practice and a general high grade of efficiency.

Finally, the technique of recording the eye-movements is relatively simple. By using the corneal reflection as the registering medium, there is absolutely no discomfort to the patient and no unusual stimulus to excite him, while the real purport of the experiment may be entirely hidden under the instructions to the patient to read exposed figures, letters, or short words, or simply to try if he can see anything at all on the black screen.

On the other hand, the photographic procedure is not without some difficulties of its own. The eyelid may droop and interfere with the recording light without parallel interference with vision. Excessive head-movements may render a considerable portion of the plate illegible or take the patient out of focus of the recording camera. But the records themselves are their own vindication, and we venture to believe that those who can appreciate the experimental difficulties of securing trustworthy comparative data will find some satisfaction in our results, and reasonable ground for expecting more of the general procedure in the future.

The most serious limitations of our technique arise from defective vision. Just how far this may finally be found an embarrassment it is difficult to predict, since the technique permits some use of correcting glasses. The series of experiments we undertook was planned to render a considerable range of visual defects indifferent; nevertheless, in three cases we were compelled to abandon the tests because of gross refractive errors.

For both of us the most surprising feature of the experiments was the conduct of the patients during the tests. We anticipated a considerable variety of troubles, particularly from the maniacal patients, and safeguarded the apparatus in a number of entirely unnecessary ways. Naturally the worst cases of maniacal excitement were not requisitioned; but, as will later appear in detail, we succeeded in getting excellent records from patients that in the wards appeared utterly impossible.

In only two cases did we encounter any unwillingness to participate in the tests. Something about the experiments seemed to appeal to the patients. The majority were helpful in getting into position and maintaining it. Many seemed thoroughly to enjoy the sessions; some were interested in the results; some were more sensitive than others to the blue light, as was evidenced by an occasional increased tendency to wink or to withdraw entirely from the apparatus, but the light was stopped down by blue glass so that continuous fixation produced only a mild and inoffensive after-image. Many of the patients apparently failed to notice it.

APPARATUS AND TECHNIQUE.

The registering device for recording the eye-reactions was a modification of the Dodge photochronograph which was designed by one of the authors, and has been used by him practically in its present form during the last five years.

As used by us it consisted of an enlarging camera of fixed length (about 5 ft. [153 cm.]) fitted with a Bausch and Lomb convertible protar, Series VIIA. The device for producing a regular motion of the sensitive photographic plate was the Dodge-Cline falling plate-holder It consists of a light-tight box 2 ft. (61 cm.) high and 7 in. (17·8 cm.) wide, fitted with opaque slides, and capable of quick adjustment to the rear of the enlarging camera like a regular plate-holder. Within the box a movable frame, holding a 5 in. (12·7 cm.) by 7 in. (17·8 cm.) photographic plate, slides vertically on two brass tracks, so adjusted that all lateral play is taken up by springs. The movement of the sliding plate frame is accurately controlled by a simple hydrostatic device. The frame is attached to a piston-rod ending in a plunger which works in a vertical cylinder of lubricating oil. The valve of the plunger offers no resistance as the latter is raised through the oil, but it absolutely resists every effort to force it downwards. The release of the plate is effected by opening a stop-cock below the plunger, when the weight of the plate-holder forces the oil out of the cylinder at the bottom through the stop-cock, and returns it to the top of the cylinder above the plunger. The velocity of the fall is determined by the opening of the stop-cock, the viscosity of the oil, and the weight of the frame and plate.

The photographic record is made on the falling plate by photographing the image of an electric arc as it appears at the cornea of the eye. The rays of the arc light are first passed through blue glass screens to eliminate the photographically useless but physiologically disturbing rays of the lower spectrum. Those rays which are then reflected from the convex surface of the cornea to the camera are brought to a focus on the photographic plate by the lens of the enlarging camera.

A convenient and well-nigh necessary modification of the plate-holder was introduced for the first time in the present experiments. Since one cannot presuppose much coöperation on the part of the insane in finding and maintaining the proper position of the head, it was found impossible to rely on methods of focusing that were satisfactory for normal subjects. A focusing and finding glass was consequently introduced into the falling plate-holder just below the photographic plate, and in the same plane. A system of automatic screens was arranged, so that during the focusing process the plate was entirely protected from light. In this way we could quietly await the opportune moment and quickly adjust the apparatus to changes in the patient's position. The apparent movement of the corneal reflection is slightly less than half the actual movement of the eyes.[1]

But the actual displacement is magnified by the enlarging camera so that the total record is a continuous curve whose amplitude is about three times the actual amplitude of horizontal eye-movements, and whose height is determined by the velocity of the plate. Under the above circumstances, continuous visual fixation will be recorded as a straight vertical line on the falling plate, while any horizontal movement of the eyes will be indicated by an oblique line whose obliquity depends on the relative velocity of the horizontal and vertical components.

The difference in illumination between the corneal reflection of the arc light and its background is sufficiently marked, so that on a perfect plate there is no trace of other impressions except the record made by the corneal image of the arc light. This should appear as a fine black hair-line on an almost clear background. No limit has been reached in the number of records one plate will hold, except the purely mechanical confusion of the lines.

In our experiments the stimulus was so arranged as to begin coincidently with the beginning of the record. When the velocity of the plate is known, the duration of an eye-reaction will be given by the height of the vertical line of eye-fixation between the beginning of the record and the beginning of the oblique line of eye-movement. The velocity of horizontal eye-movement should be given by the obliquity of the line of eye-movement, *i.e.*, the time, as measured by the fall of the plate, between one fixation and its successor.

Two series of records were made. One depended for its time-record on the measured length and obliquity of the lines. In the other an interruption of the recording light by a tuning-fork gave the time directly in vibrations of the tuning-fork. Notwithstanding a complex system of controls, our first records of the angle-velocity of the eyes by the former method involved such serious sources of error that we were reluctantly constrained to abandon them as practically useless. They do not appear in this report. The reaction-records, on the other hand, were about equally satisfactory in both series. Each record involves a probable error of less than 0·01 second.

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[1] For the mathematical theory of the movements of the corneal reflection and empirical tests of its accuracy as a measure of eye-movements, *see* Dodge: "Experimental Study of Visual Fixation" [8].

In convenience of control and in general trustworthiness the tuning-fork interruption of the recording light is a decided advantage. It was arranged as follows:—

An arc light, with horizontal upper carbon, was mounted on a heavy optical bench behind a large condensing lens. In front of this lens, and at the point where the latter brought the rays of the arc light to a focus, was placed an opaque screen with an opening which was so shaped and oriented that at each vibration of an electric tuning-fork (a tested Koenig tuning-fork of 100·12 c.-p. per second) the opening was alternately opened and closed to the passage of the light from the arc. A second smaller lens of 6 in. focus was so placed as to render the transmitted rays parallel. From the position of the subject one isolated vibration of the fork exposed the arc light and cut it off again. With this interrupted light, when the tuning-fork was in continuous vibration,

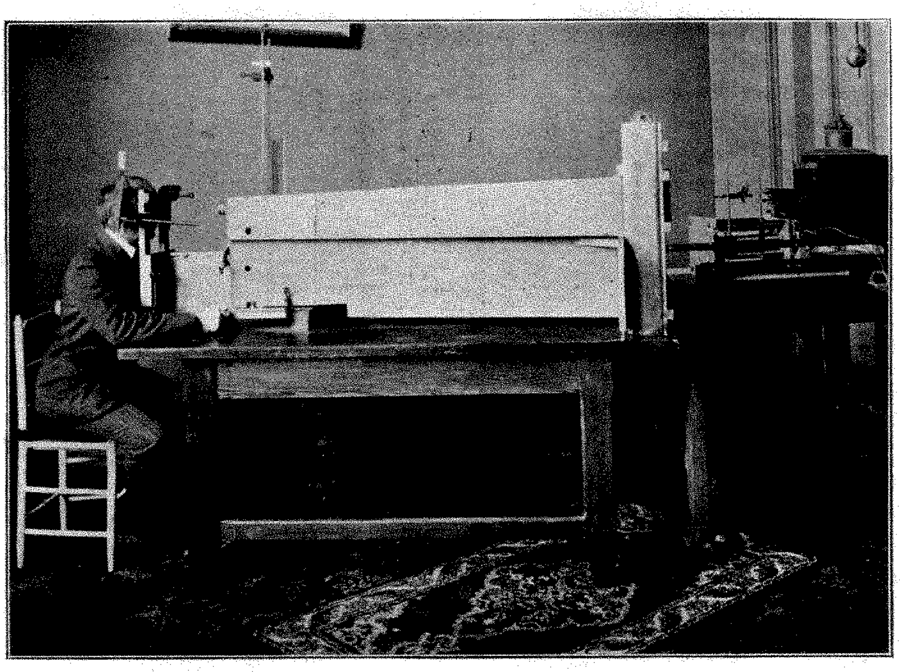

FIG. 1.
The Dodge Photochronograph.

each record of the corneal reflection appeared on the slowly falling photographic plate as a line of black points or dashes. From the beginning of one dash to the beginning of the next represented a time interval of 0·01 second. The duration of any fixation or of any eye-movement could be read directly from the appropriate record in units of 0·01 second by counting the corresponding dots.

The arc light and the tuning-fork interrupter were placed in one corner of the laboratory at a distance of about 15 ft. (459 cm.) from the patient. The patient was seated comfortably at the apparatus just in front of the enlarging camera. His head was held as firmly as practicable against a side-rest and a nosepiece. Further constraint seemed inadvisable. The resulting records were considerably complicated by head-movements, but our immediate interest was not a study of the spatial characteristics of the eye-movements, but rather a study of their temporal succession. For this purpose the records were unequivocal, except in a few cases. No patient was in the apparatus more than thirty minutes. Under favourable circumstances the tests occupied about fifteen minutes, including periods of relaxation. All records are for monocular vision. A black cardboard screen completely hid the unused eye. Three groups of tests were made on each patient at each sitting, and all three groups were recorded on the same plate. In this way each plate made a complete experimental record of a single patient at the time of examination. The plates were carefully numbered, and each number was entered in a permanent record against the name of the subject, with such additional notes of the clinical picture and conduct of the patient as seemed pertinent.

The experiment which we undertook included three tests for distinct but inter-related phenomena.

(1) Velocity of Eye-Movements.

(A) *Theory.*

The first test concerned the angle-velocity of simple reactive eye-movement. Experiments on normal individuals have shown a remarkable uniformity in the angle-velocity of similar uninterrupted eye-movements of the same person, quite independent of direct conscious effort to move the eyes fast or slowly. There are slight variations of the two eyes, and slight variations in successive movements, but under similar circumstances these variations are relatively small.

The first published records of the angle-velocity of the eye-movements noted a slight but clear slowing up of a rapid succession of eye-movements toward the end of a series of ten movements. This was tentatively attributed to fatigue. A series of records taken in connexion with a hitherto unpublished study of fatigue confirmed the previous findings and justified the hypothesis that retardation of the velocity of the eye-movements is a phenomenon of fatigue.

Valuable as they undoubtedly would be, it was hardly to be expected that adequate fatigue tests could be obtained from the insane. On the other hand, it seemed plausible that the different disease processes, in so far as they affected the psychomotor processes at all, would variously affect the angle-velocity of the eye-movements. It also seemed probable that such variations in a type of movement which is equally practised for all subjects and is almost entirely removed from the effects of voluntary caprice, would furnish exceptionally trustworthy comparative data.

Naturally, our immediate interest centred in patients suffering from maniacal-depressive insanity, where, as a matter of fact, the most marked variations from normal velocity were found, but the results of the test in other disease-processes are not without interest.

(B) *Experimental Conditions.*

The test for the angle-velocity of the eye-movements necessitated the experimental production of a considerable number of rapid reactive eye-movements of the first type (Dodge [7]) of approximately the same amplitude. Taking advantage of the fact that rapid eye-movements separate the fixation-pauses (or moments of clear vision) in reading, we satisfied the experimental requirement by exposing a succession of isolated numerals in two different parts of the field of regard about 25° apart. The reading of one numeral by the patient was the signal for the operator to cover it and to expose another 25° from the former. When the latter was read, it in turn disappeared and another was exposed where the first had been.

The eyes rarely moved through the entire 25° from numeral to numeral in a single rapid eye-movement. This was entirely congruent with the known facts that practically every long eye-movement involves more or less final readjustment in the form of short corrective movements. When the object of interest is relatively obscure, like a numeral 25° from the fixation-point, the normal end-corrective movements will vary from 1° to 5°. In the great majority of cases the corrective movement is in the same direction as the initial movement. This indicates that the initial movement was too short. If the corrective movement was negative, or if it exceeded one-sixth of the total displacement, the record was discarded. The average main corrective movements in our accepted records is about 3°. This reduces the average displacement corresponding with our records to about 22°.

A large black screen was placed at 18 in. (45·75 cm.) in front of the subject, at one side of the camera. This screen was permanent and served all three experiments. It was pierced by three openings in the same horizontal line. Two openings for the exposure of objects were 8 in. (20·4 cm.) apart. The middle opening for the passage of the blue recording light was 5½ in. (14 cm.) from the left hand opening and was lost in the blind spot of the right eye when the centre of the left hand opening was fixed. This arrangement with respect to the blind spot was designed to lessen distraction by the light during the preliminary focusing of the camera. A movable black cardboard screen behind the permanent fixed screen carried a series of numerals. These were so oriented that as the screen fell, step by step, the numbers were successively exposed at the appropriate openings of the fixed screen. The movements of the screen were regulated by the operator. The signal to the operator was the reading of the exposed numerals by the subject. The amplitude of each movement of the screen was automatically regulated by an appropriate escapement.

Before each series of experiments two numbers were exposed respectively in the left and right hand opening, the middle one being closed. The patient was told that other numbers would appear in the same places, and that these were to be read aloud as rapidly as possible. Foreigners were encouraged to use the most familiar language. With the initial movement of the screen the middle opening was uncovered, allowing the subdued arc light to illuminate the subject's eye. Four groups of these movement-records were taken for each subject, making, when all the lines were legible, twenty-four movements. This number was unnecessarily large, since the mean variation is regularly less than half of the unit of measurement, but a tendency to coördinate winking just at the time of eye-movements together with head-movements and interrupted eye-movements made some of the individual records useless.

Since the illumination of the subject's eye was the condition of a photographic record, the simultaneous exposure and illumination were a mechanical guarantee that the beginning of the photographic record was synchronous with the appearance of the stimulus to eye-movement. This arrangement gave the chief instrumental condition for the second and third series of experiments to determine the reaction-time of the ocular movements.

(c) *Results.*

Table I. shows the average duration of eye-movements of *cr.* 22 for nine normals, twenty-one maniacal-depressives, in both the maniacal and depressive phases, four cases of dementia præcox of the hebephrenic type, four epileptics, six paretics and one imbecile.

Under each form of insanity the data are arranged according to the severity of the disease. The most marked cases come first. Each case is described at length under the corresponding number in the Appendix, pp. 475 to 488. All time-values are given in $\frac{1}{1000}$ second.

TABLE I.

NORMAL.		
1	R. D.	59
2	A.	59
3	Wh.	61
4	Wr.	60
Female Nurses.		
9	Ll.	60
10	E. F.	54
Male Nurses.		
11	W. S.	62
12	J. R.	60
Recovered Patient.		
17	M. D. (*c*)	60
Average		59
Low		54
High		62
M. V.		1·5

MANIA.[1]		
Marked.		
13	S. S.	59
14	J. C.	44
15	W. B.	60
18	T. S.	51
19	J. G.	55
Average		54
Less Marked.		
31	L. K. (*b*)	60
21	A. H.	56
27	M. G. (*c-d*)	47
33	K. B. (*b*)	59
Average		55
HYPOMANIA.		
22	G.	50
29	R. R. (*a*)	65
23	A. T.	76
20	S. K. (*c*)	51
24	P. B.	61
25	P. R.	70
Average		62
Low		44, marked
High		76, hypo.

DEPRESSION.[2]		
Marked.		
26	H. N. (*a-c*)	55
32	P. F. (*a*)	74
29	R. R.	77
Average		69
Less Marked.		
33	K. B.	72
Slight.		
34	T. B.	51
High		77—marked
Low		51—slight

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[1] Maniacal phase of maniacal-depressive insanity.

[2] Depressed phase of maniacal-depressive insanity.

Dementia Præcox.		
	Marked.	
36	A. R.	62
37	M B.	52
	Moderate.	
40	G. L.	60
41	M. F.	50
	Slight.	
42	B. M.	56
Average		56

Dementia Paralytica.		
	Marked.	
43	D. D.	54
44	W. H.	53
45	A. B.	60
47	A. S.	60
Average		57
	Less Marked.	
48	J. P. E.	54
49	J. A.	49
Average		51

Epileptic		
	Moderate.	
51	G. L.	67
52	J. F.	64
53	H. O.	67
54	M. B.	80
Average		69
Imbecile.		
57	R. H.	60

From the preceding table (I.) it is obvious that the velocity of the eye-movements of maniacal-depressive patients does not vary exactly with the degree of depression or of maniacal excitement which they present. On the other hand, it should be noted that there is some variation even among normal persons. In any fair evaluation of our data, then, one must allow at the outset for some individual variations, independent of all disease. The origin of these individual variations is at present a matter of conjecture. Earlier studies [6, 9] demonstrated that the differences between individuals are not absolutely constant for different angles of movement, or for the same angle of movement at different times. But these variations are relatively small, and are due, in part at least, to minor variations in the action of opposed and coöperating muscles which are not further analysed, and which may be grouped together for our purposes as chance variations. But after due allowance is made for these chance variations, the grossness of the variations in the insane and certain very obvious tendencies in different diseases and in different phases of the same disease indicate some causal interdependence with the disease itself.

While it would be injudicious to regard these tendencies as settled before our data have been materially increased, the marked variations of the extreme maniacal and the extreme depressive states may safely be regarded as characteristic. This appears not merely from Table I., but still more convincingly from the history of such cases as 26, H. N., p. 481; 29, R. R., p. 482; and 33, K. B., p. 484. So again both patients suffering from dementia præcox and dementia paralytica have abnormally rapid eye-movements, while the epileptics are notably long. The slow eye-movements of the extreme depressives and the quick eye-movements of the extreme maniacal coincide with the general psychomotor disturbances as they appear in the familiar clinical picture of these psychoses. Quantitative evidence of abnormal quickness of maniacal movements has, however, hitherto been conspicuously lacking. On

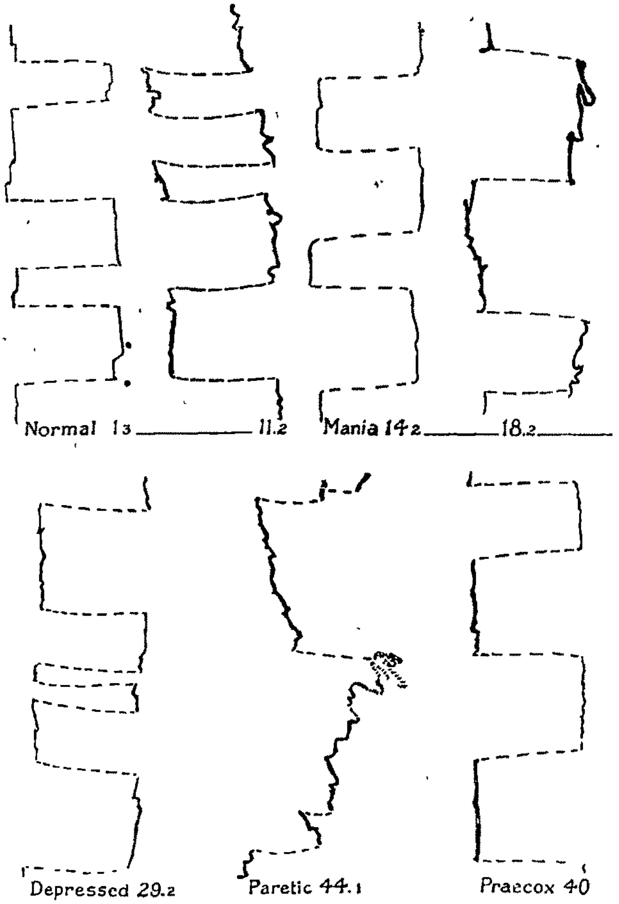

Plate I.

Plate I. is a reproduction of typical records of eye-movements. The records were projected by lantern and drawn from the projected image on a much enlarged scale. These drawings are here reproduced by process on a somewhat reduced scale. The resulting lines reproduce the original records very well, save that the dashes are relatively fainter grey in the records. The exact shape of each dash is not accurately reproduced. In all cases which are represented in Plate I. the photographic plate was moving so slowly that the dots run together in the vertical lines, appearing as dashes only during eye-movement. The dashes represent flashes of light succeeding each other every 0·01 second. The paretic line, No. 44·1, is an extreme case of head-movement and broken lines. The broken movements are typical, the head-movements less so.

the other hand, it is again congruent with the disease-picture that the eye-movements, which we have found to be rapid, are secondary automatic acts, not those that require conscious direction and control such as have hitherto been measured; and it certainly corresponds closely with our general knowledge of the diffusion of the sensory impulses and the interaction of the higher and lower nervous centres, that these secondary automatic movements should reach their extreme velocity when the interaction of the higher nervous centres is lessened.

The slowness of the eye-movements in the depressives and in the epileptics cannot be accounted for conversely by excessive interference of the higher centres. It seems rather to be the expression of a more widespread involvement resulting in a general inefficiency of the whole psychomotor system and including not only the higher centres, which appeared to be chiefly involved in mania, but also the lower centres, the simple reflexes, and the automatic acts.

Beside the mere differences of velocity in the eye-movements, there are certain characteristic tendencies in form and accuracy of eye-movement that our technique was not designed to measure, but which may be mentioned in passing. Along with the increased velocity in the maniacal eye-movements, there is a parallel tendency to abnormal overshoots such as were first described in normal persons by E. B. Huey [3]. Depressive eye-movements are more regular and symmetrical. The eye slides up into the new position as though against a gradually increasing resistance.

The eye-movements of the grossly demented show marked inaccuracies of fixation. Advanced dementia paralytica has curious inconsequential fixations, breaking the normal eye-movements at irregular points.

(2) OCULAR REACTION-TIME TO NEW PERIPHERAL STIMULI.

The second test concerned the simple reaction of the eye in responding to a peripheral stimulus. Like the first test, the second also depended on the regular and usually wholly unconscious habit of fixing a numeral or letter one is expected to read.

(A) *Experimental Conditions.*

The procedure was as follows: A figure 6 was exposed in the left hand slit of the permanent screen. The subject's attention was directed to it with the instructions that other figures, which would appear at one side or other of the 6, must be read as rapidly as possible. With the final warning to look sharp, the 6 suddenly dropped out of sight and 1 in. (2·5 cm.) to the right or left there appeared a different numeral. The exposure apparatus resembled that used in the first series of experiments. A special exposure screen was prepared so as to expose one figure (6) at the centre of the left hand opening in the permanent screen when the exposure screen occupied its primary position. A series of numbers was pasted on pieces of black cardboard which could be slipped into place either to the right or left of the 6 and just so far above it as would bring them into view by one stroke of the escapement. It only required ½ in. (1·25 cm.) movement of the exposure screen to carry the 6 out of sight and so expose the new number. The movement was so rapid that it seemed like an instantaneous change. Without the appearance of motion in any direction, the one seemed to disappear and the other was in place. The same movement of the exposure screen uncovered the arc light and began the photographic record. Simply counting the dashes of which the record was composed from the beginning of the record to the beginning of the eye-movements to fix the new number gave the reaction time of the eye in 0·01 second. A similar experiment is described more in detail in Dodge's "Experimental Study of Visual Fixation" [8]. Vocal reaction to printed matter or to isolated words, such as Dodge studied, seemed inexpedient in these tests on account of gross differences in education. Four ocular reactions were taken for each subject. Unfortunately, in some cases extreme head-movements made some of the records uncertain, while winking made other records useless. These two disturbances combined materially to reduce the number of available records.

The small number of reactions for any one individual is a serious limitation to the use of our data. If we had the work to do over again, we are agreed that we should venture to increase the number of simple reactions. Our reason for limiting the number in the present tests was the consciousness that we were dealing with subjects who were abnormally susceptible to fatigue of attention. To some of them even four tests of the same kind seemed many. For the sake of comparison, we ran through a series of ten reactions each with two more tractable cases. The results show that, in these two cases at least, the smaller number did no violence to the facts. In later discussions it will appear that minimal reactions and the general variability are quite as important as the rather meaningless averages.

(B) *Results.*

TABLE II.

Simple Ocular Reactions to Peripheral Stimuli.

(1) NORMAL.

1	R. D.	200
2	A.	200
3	Wh.	215
4	Wr.	210
Average		206
5	H.	192
6	T.	249
7	Wi.	140
8	C.	247
9	Ll.	223
10	E. F.	195
Average		208
11	W. S.	198
12	J. R.	225
Average		211
17	M. D.	222
Average		222
Average		209
High		249
Low		140

(2) MANIA.

	Marked.	
13	S. S.	205
14	J. C.	210
	,,	217
16	M. M.	225
17	M. D. (*a*)	250
18	T. S.	250
19	J. G.	210
20	S. K. (*b*)	229
Average		224
	Less Marked.	
31	L. K. (*c*)	260
21	A. H.	215
27	M. G. (*d*)	257
33	K. B. (*b*)	219
Average		238
	HYPOMANIA.	
22	G.	230
23	P. A.	225
20	S. K. (*c*)	202
24	P. B.	170
25	P. R.	230
Average		211
Average		224
High		260
Low Hypo.		170

(3) DEPRESSION.

	Marked.	
26	H. N. (*a*)	250
27	M. G.	295
29	R. R. (*c*)	173
	Less Marked.	
32	P. F.	379
	Slight.	
34	T. B.	293
17	M. D. (*b*)	204
Average		266
High		379
Low		173

(4) DEMENTIA PRÆCOX.

	Marked.	
36	A. R.	240
37	M. B.	185
38	R. B.	258
Average		228
	Moderate.	
39	A. McI.	276
41	M. F.	220
	Slight.	
42	B. M.	152
Average		222
High		276
Low		152

(5) DEMENTIA PARALYTICA.

	Marked.	
43	D. D.	370
44	W. H.	237
45	A. B.	225
47	A. S.	237
Average		267
	Less Marked.	
48	J. P. E.	190
49	J. A.	217
Average		203
	Remission.	
(50	F. A.	193)
Average		246
High		370
Low		190

(6) EPILEPTIC.

	Moderate.	
51	G. L.	298
52	J. F.	228
53	H. O.	195
54	M. B.	197
Average		229
High		298
Low		195

(c) *Discussion of Table II.*

The simple ocular reaction-time is long. According to our records the normal average lies above 200σ. In strict accuracy this average is undoubtedly too high, and should be reduced by a constant instrumental error of about fifteen. This error is involved in the form of the exposure of the peripheral stimulus. We have not tried to correct it, since it applies equally for all subjects, and our interest lies mainly in comparative rather than absolute time estimations. But after all corrections are made, these records agree with all the available data, and the simple ocular reaction-time is long.

One might *a priori* have expected that a reaction which is at once so common and apparently so necessary to the welfare of the individual in the conduct of life would be short. On the other hand, it must be noted that each ocular reaction to peripheral stimuli involves a considerable sensori-motor elaboration of the stimulus. The adequate reacting eye-movement is not only in a definite direction, but it is also of definite extent. The accuracy of the eye-movement does not now concern us, since we measure in reaction-time only the beginning of the reactive movement. But the beginning of every eye-movement is really only the initial phase of a movement of definite direction and extent. Before the eye starts, the elaboration of that particular motor impulse must be relatively complete. An accurate account of the correspondence between reaction-time and reaction-accuracy is a desideratum.

In a sense, every ocular reaction to a peripheral stimulus is not a simple reaction at all, but an individual adaptation to a change in the environment. In the past, such a reaction would have borne the misleading name of a "choice reaction." The length of the simple ocular reaction, then, is not an anomaly. It corresponds directly with the complex but automatic elaboration of the sensori-motor impulse.

Abnormal reactions may result from an indefinite number of changes within this complex sensori-motor process. This is at once the inspiration and the danger of every interpretation of complex reactions. In view of the possible complications, the relatively small mean variation for normal subjects points to a relatively stable normal oculo-motor systematization. It emphasizes at the same time the gross variations of the insane.

The small number of *per capita* records forces us to consider the reactions, as we were led to consider the velocity of movement by groups rather than by individuals. Furthermore, we will again limit our generalizations to such gross variations as are inexplicable on the basis of chance variations.

The most conspicuous comparative feature of the results is the abnormally long reactions of the maniacal-depressive patients. Not only do they average long, but, with one exception, the average reactions of both the extreme and the less marked maniacal, and of all the depressed with one exception, are above the normal. These data are not novel. They agree with the reaction experiments of Franz.

In view of the unequivocal testimony of the averages, it is somewhat disappointing to note that there is no direct correspondence between the duration of the ocular reactions and the clinical judgment of the severity of the disease. It is hardly an accident that in spite of the high averages in cases of mania the most extreme maniacal excitement had the shortest ocular reaction; while the maniacal group, which averages the longest, is that of the less marked excitement. In view of the complication of the reaction-process and the number of unanalysed factors, we feel that any hypothesis of the effect of the disease on the reaction must be regarded as tentative. But on grounds which will appear most clearly in the discussion of the pursuit-reactions, we believe that the inconsequential reactions of maniacal excitement are due to opposed tendencies in the inter-relation of the superior and the secondary central systematizations.

(3) OCULAR PURSUIT-REACTIONS.

(A) *Theory.*

The third series of tests was a reaction experiment of unusual character. The simplest and, in the end, also the most complex ocular reaction with which we are acquainted is the pursuit-movement in reaction to a moving pendulum.

It is the simplest, in the sense that no new object of regard is furnished as stimulus for reaction. There is no change in the object of attention. An object is fixed, and the fixation lapses through the movement of the object fixed. The re-establishment of the lapsed fixation involves a form of ocular reaction such as occurs on an average several times a minute throughout the waking day, either because the object moves or because of involuntary displacement of the eyes by bodily movements. Pursuit-reactions, as we may call them, normally involve a reaction-time slightly longer than the simple reactions to peripheral stimuli. At least one factor tending to lengthen the pursuit-reaction appears directly in the form of the stimulus. The stimulus to reaction is not given in the release of the pendulum, but only when, after release, the pendulum has moved some appreciable distance. The amount of movement that will constitute a stimulus to pursuit will depend on the training of the subject and the accuracy with which he maintains his fixations.

Paradoxical as it might at first seem, the total pursuit-reaction finally involves more extensive psychomotor elaboration than any other ocular reaction that we know how to produce. As is now well known (Dodge [7]), the true pursuit eye-movements are totally different in function and character from the rapid reaction-movements of the eyes by which peripheral objects of interest are fixated. The rapid movements are relatively constant in duration, and they constitute moments of practical blindness. The reason for this eye-movement blindness is still under discussion. There is no debate concerning the fact. The pursuit-movements, on the other hand, vary in angle-velocity with the angle-velocity of the moving object. The eyes move fast or slowly as the object moves fast or slowly. Moreover, the pursuit-movements are pre-eminently moments of relatively clear vision. It is because we wish to see an object clearly that we move the eyes as the object moves and keep its image on retinal areas of relatively clear vision. Furthermore, the psychomotor elaboration of the simple ocular reaction is fixed by the long-established habit of bringing excitations of the peripheral retina to areas of clear vision. The psychomotor elaboration of the pursuit-movements, on the other hand, is in practically each instance of pursuit an unique pyschomotor problem. The reaction to pursuit is fixed and habitual enough, but the velocity of the eye which shall correspond to the velocity of the object at the distance it chances to be can scarcely ever be a motor habit. To be a successful pursuit there must be an adaptation of the general pursuit tendency to the peculiar condition of each separate instance. Especially in the pendulum pursuit-movements are these conditions so various as to present, in each new case, practically unique conditions. Angle-velocity, apparent amplitude, and period of oscillation would all be alike only if pendulums of the same length swing through the same arc at the same distance from the eye of the observer. Yet unique as each case actually is, a normal eye will fall into an adequate pendulum pursuit-movement with surprising quickness and accuracy. In every normal individual the very first fixation after the initial reaction to a moving pendulum has the characteristic true pursuit-slide, even though it usually corresponds in angle-velocity to the first part of the pendulum swing, and is consequently too slow. Let us emphasize the fact: for normal individuals, however inadequate the first attempt to fix the moving object may be, it always has the characteristics of a true pursuit-movement (*see* Plate 2, lines 1, 10, 11).

The return swing of a second pendulum is usually followed with precision, except at or near the middle of the arc of oscillation, when one or two short, sharp, rapid movements break the simple pendulum pursuits. The character of these pendulum pursuits scarcely alters, even after a large number of experiments under the same objective condition. Each new pursuit seems to be solved *de novo*, and the short-lived motor habits involved in every adequate pursuit seem to be lost when the pursuit is interrupted [8].

This ability to elaborate adequate pursuit-movements, *i.e.*, to adopt an adequate motor response to the peculiar situation presented by the rhythmic movements of an object, varies widely in mental disease. In some respects, the most marked variations are found in the pendulum pursuit-movements in dementia præcox, where a marked hesitation to fall into the swing of the pendulum was found even in the mildest cases. While this peculiarity is apparently not absolutely restricted to dementia præcox, it was found in other patients only where the disease-process has produced marked deterioration.

(B) *Experimental Conditions.*

The instrumental device for producing the pursuit-reaction and the subsequent pursuit-movements was a number attached to the bob of a second pendulum. The latter hung just in front of the fixed screen with its axis vertically above the middle point between the extreme left and right hand opening. Before the experiment the pendulum was held out of equilibrium in front of the left hand opening by a simple catch attached to a falling screen in the usual place behind the fixed screen. This falling screen was released by the operator, as in the other experiments, and the release of the screen simultaneously started the pendulum and opened the way for the recording beam of light. In every case the patient was previously shown how the pendulum moved and was then requested to watch the number closely, to keep his eyes on it, not to lose it, watch it, &c.

(c) *Results.*

TABLE III.

Ocular Reactions in Pursuit of a Moving Stimulus.

(1) NORMAL.

1	R. D.	198
2	A.	238
3	Wh.	243
4	Wr.	210
Average		221
5	H.	274
6	T.	284
7	Wi.	216
8	C.	225
9	Ll.	265
10	E. F.	285
Average		258
11	W. S.	235
12	J. R.	223
Average		229
17	M. D.	223
Average		239
High		285
Low		198

(2) MANIA.

Marked.

13	S. S.	190
14	J. C.	225
	,,	222
16	M. M.	343
18	T. S.	217
19	J. G.	225
20	S. K.	314
Average		248

Less Marked.

31	L. K. (*c*)	260
21	A. H.	217
27	M. G. (*c-d*)	305
33	K. B. (*b*)	255
Average		259

HYPOMANIA.

22	G.	210
29	R. R. (*a*)	220
23	P. A.	240
20	S. K. (*c*)	212
24	P. B.	155
25	P. R.	273
Average		218
Average		240
High (marked)		343
Low (Hypo.)		155

(3) DEPRESSION.

Marked.

27	M. G.	379
28	M. C.	255
29	R. R. (*c*)	230
30	L. W.	339
Average		301

Less Marked.

Slight.

34	T. B.	303
17	M. D. (*b*)	272
Average		287
Average		296
High		379
Low		230

(4) DEMENTIA PRÆCOX.

Marked.

36	A. R.	305
37	M. B.	195

Moderate.

39	A. McI.	207
40	G. L.	260
41	M. F.	215

Slight.

42	B. M.	275
Average		243
High		305
Low		195

(5) DEMENTIA PARALYTICA.

Marked.

43	D. D.	445
44	W. H.	240
45	A. B.	224
47	A. S.	267

Less Marked.

48	J. P. E.	227
Average		281
High		445
Low		224
Average excluding high		239

(6) EPILEPTIC.

Moderate.

51	G. L.	260
52	J. F.	222
53	H. O.	230
54	M. B.	221
Average		238

TABLE IV.

Table of Comparison of Averages.

	Mvt.	Reactions	Pursuit-reactions
NORMAL.	59	209	239
MANIA. *Marked.*	54	224	248
MANIA. *Less marked.*	55	238	259
HYPOMANIA.	62	211	218
DEPRESSION. *Marked.*	69	239	301
DEPRESSION. *Less Marked and Slight.*	61	295	287
DEMENTIA PRÆCOX. *Moderate, Marked and Slight.*	56	222	243
DEMENTIA PARALYTICA. *Marked.*	57	267	294
DEMENTIA PARALYTICA. *Total.*	55	246	281
EPILEPTIC.	69	229	238

(D) *Discussion of Table III.*

In all classes except in moderate depression the pursuit-movement reaction averages longer than the simple ocular reaction. The differences between the two, however, are not constant. Even in the group of normal persons the differences are not constant. The variations, however, allow of some degree of classification. It must be remembered that the stimulus to pursuit-movement is not mechanically fixed as was the stimulus to a new peripheral stimulus. The movements of the pendulum operate as a stimulus to pursuit only when the lapsed fixation in some way makes itself felt through the indistinctness of the object. For the trained observer it operates almost immediately. For the less trained it operates only after the pendulum has moved some clearly appreciable distance. The mean difference between pendulum- and pursuit-reactions for normal observers under the conditions of our test was approximately 30σ. This average difference holds approximately the same for præcox and for the longer reactions of paresis. It does not hold for maniacal-depressives. But the individual variations are so great that the maniacal-depressive differences can scarcely be spoken of as characteristic. It does, however, constitute additional evidence of a high degree of disturbance of those complex superior central processes which are usually grouped under the general name of attention. Further evidence to the same effect comes from a consideration of minimal reactions, which are given in Table V.

TABLE V.

Table of Minimal Reactions.

NORMAL.		
1	180	180
2	180	200
3	206	230
4	200	200
5	166	260
6	230	273
7	128	179
8	243	179
9	200	240
10	180	260
11	140	200
12	210	210
17	220	190
Average	191	216

MANIA.		
13	180	180
14	180	180
16	186	257
17	205	
18	210	200
19	160	210
20	182	257
	186	214
31	230	240
21	190	210
27	230	280
33	190	190
	210	230
22	210	200
23	210	200
20	190	200
24	150	140
25	210	220
	194	192
Average	195	211

DEPRESSION.		
26	200	
27	279	244
28		228
29	170	210
	216	227
34	240	300
17 (*b*)	186	248
	213	274
Average	215	246

DEMENTIA PRÆCOX.		
36	200	260
37	180	190
38	248	
39	260	167
40		240
41	200	180
42	150	230
Average	206	211

DEMENTIA PARALYTICA.		
43	350	290
44	220	200
45	210	210
47	230	240
48	170	210
49	180	
50	180	
Average	220	230

EPILEPTIC.		
51	270	250
52	200	200
53	190	210
54	170	200
Average	207	215

Discussion of the Table of Minimal Reactions (Table V.).

In some respects the minimal reactions for any well-established type of reaction is more instructive than the average reaction. The minimal reaction shows the reflex systematization in its highest state of efficiency. The mean reaction indicates the average state of efficiency. The two differ from one another by the mean value of all those disturbing elements that may complicate the reaction-process. It seems to the writers a very significant fact that the average minimal reaction of extreme maniacal excitement is below the average minimum of normal subjects. It is not much below the normal, but it is not above it as the total average is. Moreover, the mean variation of the minimal reactions is approximately the same as the mean variations of the averages. This consistent uniformity is not accidental. In connexion with the adequate pursuit-reactions it seems to the writers to constitute unequivocal evidence that the oculo-motor systematization is not seriously disordered in acute mania. The large mean value of disturbing elements constitutes the final point that we have to offer in the cumulative experimental evidence that extreme mania involves a marked disturbance of the controls normally exercised by the superior central systematizations.

This seems to the writers to coincide closely with the general clinical picture of marked mania. The motor organization even for complex acts is not lost. The incapacity for regular employment is flagrantly due to gross disturbances of the normal controls within the higher systematizations. Tentatively, at least, we may picture this in terms of an inhibition of the free interaction of the various factors in the normal complex superior organization.

Provided there is some intrinsic retardation of the intermediate systematizations, like the simple oculo-motor reflexes, we should expect to find the total evidences of maniacal excitement less marked. In such cases we should expect the minimal reactions to be long as well as the average reactions. This is actually the case in less marked mania. It looks as though the inhibitory processes involved in the disease were affecting lower centres. The climax of this downward progression seems to be reached when, in *extreme depression*, the resistance to neural interaction involves the simplest reflexes.

In contrast to the differential increase of resistance to neural activity as found in the maniacal-depressives, our experimental data from the demented point to a general disorganization of the central systematizations.

In dementia paralytica the entire nervous system is involved in this disorganization, as is shown by the marked retardation, and the inefficiency of the simplest, as well as of the higher reflexes (patellar, pupillary, and cerebellar).

In præcox the disorganizations seem to be primarily limited to the superior systematizations. This is shown negatively by the rapid eye-movements, normal oculo-motor reactions, and positively by the difficulty of adopting adequate reactions to new conditions of the environment, as in the pursuit-movements. This latter peculiarity of præcox patients has a practical as well as a theoretical interest.

Practically, it is an important differentiating symptom between moderate maniacal excitement and developing præcox, *i.e.*, between two psychoses whose differential diagnosis is of the utmost importance and often of the utmost difficulty. Unfortunately the faultiness of the pursuit is not easily detected by direct observation. Photographic registration, although remarkably simple as a scientific technique, is rather too expensive in time and apparatus for regular professional use. If the matter prove worth while, a simplified recording apparatus is probably the only safe and practicable solution. It would seem strange,

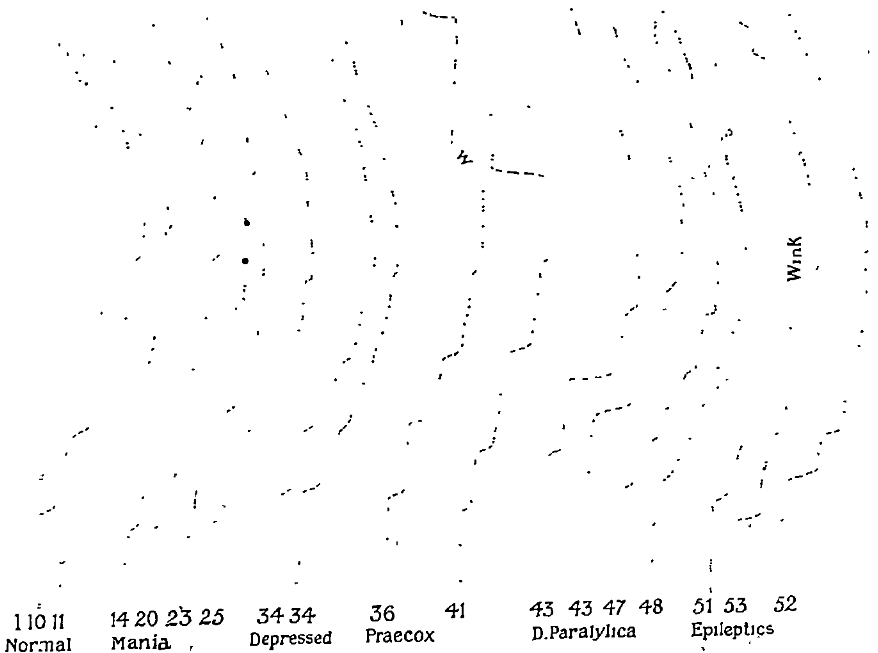

Plate II

Plate II. is reproduced from drawings of typical pursuit-reaction records. It shows most of the typical variations of the visual pursuits so far as they were not complicated by gross head-movements. The lines accurately reproduce only the general configuration of the pursuit.

Each line, reading from the bottom up, represents one complete pursuit-swing corresponding to a double oscillation of the second pendulum. Since the release of the pendulum and the beginning of the record are synchronous, the straight line at the beginning of each record gives the reaction-time. The reaction begins with a sharp horizontal movement to the right. This is followed by the slow pursuit swing, which is more or less adequate according to the nature of the disease. The præcox pursuits, Nos. 36 and 41, are typical. In mild cases the hesitation to adopt the pursuit-swing is less pronounced, but it is regularly shown by straight lines somewhere in the pursuit. The maniacal pursuit shows a tendency to get ahead of the pendulum (*see* upper part of lines 14, 23 and 25). This tendency sometimes appears in the first positive acceleration of the pendulum in maniacal cases. It is not entirely absent from normal pursuits or from moderate depression. In the latter cases, however, it is very rare. Other modifications of the pursuit are suggestive, but at present they permit no generalized statement.

The double breaks in each record are occasioned by the swinging of the pendulum through the recording beam of light.

however, if similar phenomena cannot be found in other forms of reaction which are more accessible to direct observation.

The theoretical bearing of the inadequate ocular pursuit-movements of præcox we have already mentioned. It was not overlooked by us that the simplest explanation of the phenomenon would be to coördinate it with those processes which are ordinarily grouped under the head of faulty attention. This explanation seems to us untenable on the following grounds:—

(1) Equally grave defects of "attention" exist in maniacal excitement without parallel difficulty of pursuit.

(2) The reaction-times do not indicate gross defects of "attention" in moderate præcox.

(3) Reasonable "attention" and effort at pursuit are both clearly indicated in the number and character of the short corrective movements.

Finally, the phenomenon seems to connect itself naturally with certain characteristic clinical observations of præcox as one manifestation of the patient's inability to adapt himself to new and unusual requirements of his environment. Put technically, it is the patient's inability to adopt adequate short-lived habits in response to a new recurrent situation. There is some clinical evidence that this motor phenomenon rests on a basis of faulty elaboration of the perceptual data. Our experiments indicate that the intellectual defect is a matter of inadequate appreciation rather than a matter of attention.

The writers take this opportunity to express to Dr. H. S. Noble, Superintendent of the Connecticut Hospital for the Insane, their cordial appreciation of his sympathetic interest and encouragement which made this series of experiments possible.

The Appendix contains a brief account of each case by Dr. Diefendorf, together with all the unambiguous comparative data from the photographic records.

APPENDIX.

NORMALS.

	Mvt.	Simp. R.	Pend. R.
1. R. D., practised	No. 19	200	210
	Av. 59	220	190
		180	180
		——	210
		200	——
			198

		Mvt.	Simp. R.	Pend. R.
2.	A., student	No. 13	180	200
		Av. 59	220	240
				260
			200	
				233
3.	Wh., student	No. 7	210	230
		Av. 61	230	256
			206	
				243
			215	
4.	Wr., student	No 8	230	220
		Av. 60	200	200
			210	210
			200	
				210
			210	

5 *to* 10.—*Female Nurses.*

5	H., aged 64	Series	230	292
		I. No	166	273
		Mvts.	204	260
			166	273
			192	274
6.	T., aged 65	Series	260	293
		I. No	230	273
		Mvts	256	287
			249	284
7.	Wi., aged 67	Series	153	199
		I. No	128	205
		Mvts	133	282
			148	179
			140	216
8.	C., aged 69	Series	251	230
		I. No	243	179
		Mvts.		235
			247	256
				225

		Mvt.	Simp. R.	Pend. R.
9.	Ll., aged 45	No. 26	260	250
		Av. 60	210	320
			200	250
			——	240
			223	——
				265
10.	E. F., aged 46	No. 22	180	260
		Av. 54	216	310
			——	——
			195	285

Male Nurses.

		Mvt.	Simp. R.	Pend. R.
11.	W. S., aged 38	No. 24	260	270
		Av. 62	140	220
			210	200
			180	250
			——	——
			198	235
12.	J. R., aged 39	No. 7	220	240
		Av. 60	260	210
			210	220
			210	——
			——	223
			225	

Recovered Patient.

	Mvt.	Simp. R.	Pend. R.
Sec 17, M. D. (*c*) for full record	Av. 60	222	223

MANIACAL-DEPRESSIVE INSANITY.

Maniacal Phase, Marked.

		Mvt.	Simp. R.	Pend. R.
13.	S. S., F.,[1] aged 49. Second attack of two months duration. A. T.[2]—Extreme pressure, with impulsiveness. Marked spontaneity, flight of ideas, distractibility, and irritability. I. A.[3]—Held with great difficulty. Many readjustments necessary. Shouted. Commented. Added figures.	No. 8	180	200
		Av. 59	230	180
			——	——
			205	190

[1] The letters F. and M. after the patient's initials refer to the patient's sex.

[2] A. T. gives the patient's condition *at the time* of examination.

[3] I. A. gives the patient's behaviour *in the apparatus*.

		Mvt.	Simp. R.	Pend. R.
14.	J. C., M., aged 51. Numerous attacks of maniacal phase. Present attack of two months duration. A. T.—Marked pressure. Spontaneity. Flight of ideas. Elation. Distractibility. Marked impulsiveness and destructiveness. Person smeared and naked on ward. I. A.—Surprisingly tractable and helpful. Shouted responses.	No. 16 Av. 45	(*a*) 180 240 —— 210	215 240 220 —— 225
(*b*)	Second plate several days later. Same conditions.	No. 8 Av. 43	(*b*) 200 220 230 —— 217	180 240 240 230 —— 222
15.	W. B., M., aged 30. Third attack of eight months duration. A. T.—Extreme pressure. Marked productivity and flight of ideas, distractibility, emotional irritability and elation. I. A.—Tractable, loquacious, distractible. Sluggish. Eyelids sagged. No legible reactions.	No. 5 Av. 60		
16.	M. M., F., aged 38. Second attack of two months duration. First of five months duration. Lucid interval of seventeen months. A. T.—Marked excitement. Extreme pressure. Flight of ideas. Irritable. Violent. Destructive. Untidy. Partial orientation. I. A.—Remarkable self-control. Obvious suppressed excitement. Voice loud. Many comments.	Series I. No Mvts.	186 264 —— 225	(695) 335 257 437 —— 343
17.	M. D., F., aged 26. Five years duration. For the last three years regular alternation from depressive to maniacal phase without lucid intervals. A. T.—Marked pressure. Elation. Distractibility. Flight of ideas. Noisy. Irritable moods. Tore clothing. No deterioration. I. A.—Tractable. Complained that pendulum was blurred.	Series I. No Mvts.	(*a*) 290 254 205 —— 250	

	M'vt.	Simp. R.	Pend. R.
(b) Same at second experiment. Just passed to depressive state. Slight retardation without despondency. Exaggerated feeling of incapacity.		(b)	
		186	309
		222	263
		——	273
		204	248
			273
			268
			——
		(c)	272
(c) Same five months later. Normal.	No. 19	225	(300)
	Av. 60	220	210
		220	270
		——	190
		222	——
			223
18. T. S., M., aged 67. Maniacal phase of three months duration immediately preceded by depressive phase of fourteen months duration. A. T.—Considerable pressure of activity. Busyness. Constant speech. Flight of ideas. Increased irritability, with elation. Distractibility. I. A.—Talked constantly. Responded correctly and rapidly.	No. 11	270	250
	Av. 51	270	200
		210	200
		——	——
		250	217
19. J. G., F., aged 52. Recurrent attacks for many years, both maniacal and depressive. A. T.—Maniacal phase of two months duration. Considerable pressure. Great productivity. Distractibility. Increased irritability predominating elation. I. A.—Loud responses. Movements seemed deliberate. Kept in position with difficulty. At times refuses to open eyes.	No. 8	190	210
	Av. 54	160	240
		200	——
	No. 13	290	225
	Av. 56	——	
		210	
		(b)	
(b) Same. Series of ten reactions.		No. 10 Av. 204 M. V. 11	
20. S. K., M., aged 40. Eight years duration. For last three passed immediately from one maniacal state to another, average six months duration. No deterioration. A. T.—Marked excitement. Pressure of activity. Flight of ideas and distractibility. Elation and impulsive outbreaks. Consciousness clear. I. A.—(a) Violent laughter. Intolerant of assistance.	Illegible.	(a) Too much head-movement.	
		(b)	
	Series I. No Mvts.	275	342
		261	347
		199	308
		182	257
		——	——
		229	314

	Mvt.	Simp. R.	Pend. R.
(b) Less intractable.			
(c) Same five months later. Somewhat improved. Hypomania. Tractable. Responds rapidly. Attends well.	No. 19 Av. 51	(c) 210 190 210 200 —— 202	 200 200 230 220 —— 212
Maniacal Phase, Less Marked.			
31 L. K., F., aged 63. Maniacal excitement after moderate depression. *See* description under depressive phase, less marked, 31 (*b*) and (*c*).	No. 25 Av. 60	No. 4 260	No. 4 260
21. A. H., M., aged 73. Third attack of six months duration. A. T.—Irritability, with predominating elation. Pressure of activity. Flight of ideas. Distractibility. I. A.—Very tractable. Responses correct and rapid. No evident disturbance of attention.	No. 5 Av. 56	(265) 215 240 190 —— 215	220 210 220 W. —— 217
27. M. G., F., aged 60. Moderate mania after extreme depression. *See* description under depressive phase, marked, 27 (*c*) and (*d*).	No. 22 Av. 47	No. 3 257	No. 6 305
33. K. B., F., aged 44. Moderate mania after moderate depression. *See* description under depressive phase, less marked, 33 (*b*).	No. 14 Av. 59	No. 4 219	No. 4 255
HYPOMANIA.			
22. G., M., aged 18. First attack eighteen months duration. A. T.—Slight pressure. Mischievous and boisterous. Considerable spontaneity of speech with rambling thought. Distractibility. Irritability. I. A.—Excellent behaviour. Held himself.	Av. 50	220 230 260 210 —— 230	220 210 220 200 210 200 —— 210
29. R. R., F., aged 14. Hypomania preceding marked depression. For description *see* under depressive phase, marked, 29 (*a*).	Av. 65		Av. 220

	Mvt.	Simp. R.	Pend. R.
23. P. A., F., aged 59. Many attacks, mostly maniacal, for thirty-three years. A. T.—Just emerging from maniacal phase of two weeks duration. Slight irritability, distractibility and loquacity. I. A.—Quite tractable. Commented on apparatus and added figures.	No. 19 Av. 76	230 240 220 210 225	260 250 200 250 240
20. S. K., M., aged 40. Hypomania following pronounced maniacal state. For description *see* under maniacal phase, marked, 20 (*c*).	No. 19 Av. 51	202	212
24. P. B., M., aged 27. Second attack of two weeks duration. A. T.—Moderate busyness. Slight elation. Flight of ideas, spontaneous speech. I. A.—Excellent behaviour. Good interest.	No. 6 Av. 61	150 190 170	140 170 155
25. P. R., M., aged 20. Second attack of three weeks duration. A. T.—Moderate irritability and impulsiveness. I. A.—At first irritable, then more tractable and pleasant.	No. 10 Av. 70	(390) 240 240 210 230	285 315 220 273

MANIACAL-DEPRESSIVE INSANITY.

Depressive Phase, Marked.

26.—H. N., F., aged 34. Second attack. Two months duration. Three days before test patient suddenly changed overnight from active maniacal state to stuporous state. A. T.—Profound retardation of thought, attention and action. Complete disorientation. Fogged consciousness. Feeling of inadequacy. I. A.—Somewhat resistant. Slow, partially inaudible responses. Better at end.	No. 9 Av. 53	(*a*) 235 275 250	Pursuit on second swing.
(*b*) Same next day. Condition unchanged. Responded only after urging.	No. 7 Av. 55	(*b*) 240 200 200 250 222	No pursuit.
(*c*) Same next day. Slight improvement. Series of eight reactions as test.	No. 11 Av. 56	(*c*) No. 8 Av. 206 M. V. 20	No pursuit.

		Mvt.	Simp. R.	Pend. R.
27.	M. G., F., aged 60. For years alternating attacks of maniacal-depressive insanity without lucid intervals. No evident deterioration. A. T.—Extreme despondency. Marked retardation. No voluntary speech or activity. Almost inaudible replies. Marked self-accusation. Without illusions or hallucinations. Perfect orientation. I. A.—Slow faint responses.			408 369 244 494 ——— 379
(*b*)	Same several days later. Retardation less marked. Occasional remark. Entrance and exit from room now without prodding. Reactions apparently good.		(*b*) 289 279 318 ——— 295	
(*c*)	Same five months later. Moderate mania with slight pressure. Moderate distractibility and flight of ideas. I. A.—Tractable. Poor attention.	No. 8 Av. 46	(*c*)	300 280 290 ——— 290
(*d*)	Same next day. Still more distractible owing to presence of visitors.	No. 14 Av. 48	(*d*) (420) 280 260 230 ——— 257	350 320 300 ——— 323
28.	M. C., F., aged 45. Third attack of maniacal-depressive insanity, depressive phase of nine months duration. No hallucinations, illusions or deterioration. A. T.—Marked retardation evident in attention, train of thought and volition. No voluntary speech. Meagre and slow responses. Various delusions of self-accusation. Emotionally depressed and apprehensive.			228 291 246 ——— 255
29.	R. R., F., aged 14. Numerous attacks of maniacal phase and one of depressive within last twelve months. A. T.—(*a*) Hypomania. Moderate elation, productivity, flight of ideas and distractibility. Busyness. I. A.—Tractable. Excellent reactions.	No. 12 Av. 65	(*a*)	240 190 230 ——— 220

	Mvt.	Simp. R.	Pend. R.
		(b)	
(c) Same six days later. Marked depressive stage. Profound despondency. Extreme retardation. No voluntary speech. Sluggish movement. I. A.—Timid. Shrinking from nose-piece. Responses slow, almost inaudible, and only after urging.	No. 26	230	240
	Av. 70	170	240
		170	210
		180	200
		188	222
		(c)	
	No. 20	170	260
	Av. 77	180	230
		170	210
			220
		173	
			230
30. L. W., F., aged 57. For fifteen years recurrent attacks of maniacal-depressive insanity without lucid intervals. A. T.—Depressive phase of two years duration. Pronounced retardation of thought, attention and volition. Very little spontaneous speech or activity. Deep emotional depression, without delusions. Good orientation. Some deterioration in memory and judgment. General indifference.			300
			350
			369
			339

Depressive Phase, Less Marked.

	Mvt.	Simp. R.	Pend. R.
		(a)	
31. L. K., F., aged 63. For many years alternating attacks of maniacal and depressive phases without intermissions. A. T.—Emerging from depressive attack of several months duration. Considerable retardation of thought, volition, and attention. Little voluntary speech. Low tones and slow responses were explained by patient as results of "difficulty of thought." Sad and wished to die. No hallucinations or delusions. Good orientation. Clear consciousness. I. A.—Tractable.	Series I. No Mvts.	324	302
		324	302
		(b)	
	No. 13		290
	Av. 60		260
(b) Same five months later. Maniacal excitement. Busyness. Volubility. Pronounced elation. Distractibility. I. A.—Tractable. Good attention.			240
			250
			260

	Mvt.	Simp. R.	Pend. R.
(c) Same several days later. Still more maniacal. Great pressure and productivity. Great distractibility. Difficulty in reading figures. Many mistakes.	No. 12 ... Av. 60	(c) 280 290 240 230 —— 260	
32. P. F., M., aged 28. For four years numerous attacks of maniacal-depressive insanity. At first alternate depression and elation, of several months duration, with brief lucid intervals. During past year attacks were shorter, more severe and without lucid intervals. A. T.—Marked despondency with retardation. Dejected and lachrymose. Moved from seat in ward only occasionally, after insistent prodding. Meagre replies. Complained of numbness, &c. No hallucinations or delusions. Good orientation. No deterioration.	No. 7 .... Av. 69	(a) 398 ... 360 —— 379 (b) 239 ... 155 253 —— 216 (c)	None taken. Not clear.
(b) Same several days later. Mild maniacal excitement of two days duration. Mild pressure of activity, talkativeness and flight of ideas, and distractibility. Elated. Talks of future work. Disoriented as to time. Same several days later. Another depressive phase. Refused to enter apparatus.	No. 11 ... Av. 74	Refused to react.	
(c) Same five months later. Profound retardation. Slight elation and occasional smiles. I. A.—Tractable. Good attention. Retardation too pronounced to read figures.			
33 K. B., F., aged 44. Two months duration. A. T.—Pronounced retardation of thought, attention, and volition. Self-accusatory delusions. Considerable apprehensiveness. I. A.—Tractable. Poor attention. Needed constant prodding. "Felt sleepy."	No. 5 ... Av. 72 No. 14 ... Av. 59	(a) None. ... (b) 225 ... 250 ... 190 ... 210 ... —— 219	None. 240 190 290 300 —— 255
(b) Same two days later. Moderate maniacal phase. Better attention. Responses more audible and rapid.			

Depressive Phase, Slight.

	Mvt.	Simp. R.	Pend. R.
34. T. B., F., aged 29. In third attack of maniacal-depressive insanity. First at 21 was depressive. Second at 28 was maniacal. Present attack of six months duration is mildly depressive. No deterioration. A. T.—Perfect orientation. Retardation evident in train of thought and general lack of activity. Little voluntary speech unless questioned. Speech slow and low. Profoundly dejected and somewhat lachrymose. Some self-accusation. Otherwise no delusions.	No. 13 Av. 51	250 240 390 293	300 310 300 303
17. M. D. For full description *see* under maniacal phase, marked, 17 (*b*).		204	272

DEMENTIA PRÆCOX.

Hebephrenic Marked Dementia.

	Mvt.	Simp. R.	Pend. R.
36. A. R., aged 36. Thirteen years duration. A. T.—Extreme apathy. Indolence. Paralysis of thought. Silly laughter. Blunted attention. Faulty judgment. I. A.—Poor attention. Eyes apparently wandered everywhere. In only one of the four reactions were the figures read.	No. 10 Av. 62	280 240 200 240	260 350 305
37. M. B., F., aged 32. Seven years duration. A. T.—Desultoriness. Paralysis of thought. Residuals of former erotic delusions. Occasional hallucinations of hearing. Pronounced defects of memory. I. A. — Apprehensive. Marked head-movements. Faulty attention. Figures were apparently read rapidly.	No. 12 Av. 52	190 180 185	200 190 195
38. R. B., F., aged 26. Six years duration. Marked impairment of memory and intellect. Marked emotional deterioration. Extreme paralysis of thought. Complete disorientation. Inability to care for herself. I. A.—Attention poor. Jerky head-movements. Shut her eyes and looked languidly about. Speech reactions slow or wanting. Records largely illegible owing to head-movements.	Series I. No Mvts.	268 248 258	

Moderate Dementia.

		Mvt.	Simp. R.	Pend. R.
39.	A. McI., F., aged 19. Twenty-one months duration. A. T.—Moderate dementia. Residuals of former grandiose delusions. Moderate defects of memory, paralysis of thought and will. Emotional deterioration. Oriented and without hallucinations. I. A.—Adapted herself readily to the apparatus and seemed to respond easily. Slight apparent retardation.		(415) 292 260 —— 276	246 167 —— 207
40.	G. L., M., aged 30. Several months duration. From onset moderate despondency with delusions of self-accusation, reference and persecution. Occasional hallucinations of hearing. I. A.—Excellent behaviour. Good interest and attention.	No. 13 Av. 60	(420)	290 260 240 250 —— 260
41.	M. F., M., aged 31. One year's duration. A. T.—Constant aural hallucinations. Consciousness clear. Orientation perfect. Slight defects of memory. Some paralysis of thought. Persecutory and somatic delusions. Diminished emotional and volitional activity.	No. 13 Av. 50	210 200 250 —— 220	250 210 180 220 —— 215

Slight Dementia.

		Mvt.	Simp. R.	Pend. R.
42.	B. M., M., aged 26. Twelve months duration. A. T.—Slight emotional deterioration. Laziness. Occasional silly laughter. In all other respects apparently normal and ready for discharge. I. A.—Splendid behaviour. Answered with unusual promptness, and seemed interested.	No. 17 Av. 56	150 160 150 150 —— 152	Straight. 230 320 Wink. —— 275

DEMENTIA PARALYTICA.

Marked Dementia.

		Mvt.	Simp. R.	Pend. R.
43	D. D., M., aged 42. Two years duration. A. T.—Advanced physical signs. Still able to care for himself. Totally incapable of simplest labour. *Note.*—The first two pursuits contain one straight line each.	No. 11 Av. 54	370 390 350 —— 370	290 420 550 520 —— 445

	Mvt.	Simp. R.	Pend. R.
44. W. H., M., aged 48. A. T.—Extreme dementia. Pronounced physical signs. Patient died one week later in apoplectic seizure. I. A.—Held without difficulty. Responses apparently slow.	No. 7 Av. 53	220 270 220 —— 237	280 240 200 —— 240
45. A. B., M., aged 43. Three years duration. A. T.—Advanced dementia with marked physical signs. I. A.—Held position with difficulty.	No. 2 Av. 60	220 262 210 210 —— 225	241 210 220 —— 224
47. A. S., M., aged 42. Three years duration. A. T.—Advanced dementia. Numerous physical signs. Euphoria. Still able to care for self. I. A.—Tractable. Apparently excellent attention.	No. 20 Av. 60	(370) 230 240 240 —— 237	240 310 250 270 —— 267

Less Marked Dementia.

	Mvt.	Simp. R.	Pend. R.
48. J. P. E., M., aged 60. Eleven months duration. A. T.—Considerable dementia. Marked physical signs. Defective memory. Disorientation. Paralysis of thought. Feeling of well-being. Some apathy. Grandiose delusions. I. A.—Tractable. Apparently good attention. Responses unusually rapid.	No. 5 Av. 54	210 170 —— 190	210 260 210 —— 227
49. J. A., F., aged 44. One year's duration. Demented type. A. T.—Fairly pronounced dementia with severe physical signs. I. A.—Difficult to hold in position. Indifferent and poor attention. (*b*) More interested and tractable.	No. 18 Av. 49	(*b*) 200 260 180 230 —— 217	No pursuit.

REMISSION.

	Mvt.	Simp. R.	Pend. R.
50. F. A., M., aged 43. Twelve years duration. Marked remission. Some emotional deterioration. Slightly faulty judgment. Some elation. Some spontaneity of thought. I. A.—Conduct excellent. Helpful. Read figures quickly and correctly. Marked head-movements interfered with tests 1 and 2.	Head-movements.	180 200 200 —— 193	Head-movements.

EPILEPTICS.

All Moderate.

	Mvt.	Simp. R.	Pend. R.
51. G. L., M., aged 57. Three years duration. A. T.—Moderate dementia. Faulty memory. Impaired judgment. Delusions of infidelity. Irritability. Periodic ill-humour and violence. I. A.—Splendid behaviour. Good interest and attention.	No. 19 Av. 67	330 300 290 270 —— 298	290 250 290 290 —— 280
52. J. F., aged 56. Twenty-six years duration. Within last few years moderate deterioration. Faulty impressibility of memory, and faulty judgment. Increased irritability. I. A.—Good interest and apparently normal reactions.	No. 9 Av. 64	200 210 260 240 —— 228	210 255 200 —— 222
53. H. O., M., aged 37. Epileptic convulsions at 2½ years. Mental deterioration developed at 34. A. T.—Slight defects of judgment. Increased irritability. Periodic gloominess and stubbornness. Slight defects of memory. I. A.—Tractable. Good attention.	No. 9 Av. 67	190 200 —— 195	240 240 210 —— 230
54. M. B., F., aged 38. Twenty-one years duration. Slight deterioration. A. T.—Increased irritability. Slight defects of memory. Variable moods. I. A.—Splendid behaviour. Good interest. Apparently rapid reactions.	No. 8 Av. 80	170 200 220 —— 197	240 220 225 200 —— 221

IMBECILES.

Five cases of moderate imbecility gave only very scanty material. There were, however, no cases of the præcox pursuit.

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PUBLICATIONS RECENTLY RECEIVED.

[*Notes on a book under this heading do not preclude a subsequent review.*]

L'Aphasie de Broca. Par Dr. FRANÇOIS MOUTIER. Travail du laboratoire de M. le Professeur Pierre Marie. Pp. 774. Paris: Steinheil, 1908.

This work contains an authoritative statement of the views of Professor Marie on the subject of aphasia by one of his pupils. An excellent sketch of the history of the subject is preceded by a succinct account of Professor Marie's criticism and theories. The second part of the work is devoted to Broca's aphasia and its cerebral localization. This is followed by a clinical study of its phenomena, with a summary of the cases published between 1861 and 1906. The second half of the book is taken up with the personal observations of the author, illustrated with horizontal sections of the affected brains. We hope to consider the results obtained by Professor Marie and his pupils in the next number of this Journal.

Drei Aufsätze aus dem Apraxiegebiet. Von Professor Dr. H. LIEPMANN. S. 80. Berlin: Karger, 1908.

A useful reprint of the following three papers by Professor Liepmann: "Kleine Hilfsmittel bei der Untersuchung von Gehirnkranken" (1905); "Die linke Hemisphäre und das Handeln" (1905); "Über die Funktion des Balkens beim Handeln und die Beziehungen von Aphasie und Apraxie zur Intelligenz" (1907). All these papers were alluded to in the article on "Apraxia" in *Brain*, 1908 p. 164.

Der Bau der Spinalganglien des Menschen und der Säugetiere. Von Dr. A. S. DOGIEL. S. 151, mit 14 Tafeln und 5 Abbildungen im Text. Jena: Fischer, 1908.

In this book the author puts together the results of many years' work. Much has already been published in papers contained in various journals, but it will be of great value to all who work on the structure of the nervous system to possess the author's views in so convenient a form. He deals, moreover, with the most recent questions concerning the ganglia of the posterior root such as the regenerative processes which may occur within it. The figures are unusually beautiful.

Der Unfall in der Ätiologie der Nervenkrankheiten. Von Dr. KURT MENDEL. S. 189. Berlin: Karger, 1908.

A useful little book dealing with a most difficult subject. The author considers the relation of accident to general paralysis of the insane, tumours and abscesses of the brain, tabes dorsalis, disseminated sclerosis and syringomyelia. He also deals with the effect of injury in progressive muscular atrophy, paralysis agitans, exophthalmic goitre and epilepsy. This work should be consulted by all who are about to give an opinion on the legal aspects of an accident in these diseases.

Lehrbuch der Nervenkrankheiten. Von Dr. H. OPPENHEIM. Fünfte vermehrte und verbesserte Auflage, mit 432 Abbildungen im Text und 8 Tafeln. S. 1641. Berlin: Karger, 1908.

This well-known work has been greatly improved by a large number of additions and is completely up to date. It remains the best general text-book in any language on account of the fulness with which the literature is cited. This edition should find a place on the shelves of all neurologists.

Recidivism. By J. F. SUTHERLAND, M.D. Pp. 115. Edinburgh: William Green, 1908.

This book is the outcome of four articles contributed to the *Journal of Mental Science* and of evidence given before the Royal Commission on the "Care and Control of the Feeble-minded." The nature, prevalence, and causes of recurrent crime are dealt with, and a chapter is devoted to the legal attitude towards the problem.

Nerven und Seele. Von Dr. PAUL KRONTHAL. S. 431. Jena: Fischer, 1908.

An attempt to correlate the results of microscopical anatomy with physiological and psychological facts. The first half of the book deals with the general physiology of the nervous system; the second half is devoted to psychology. As he has made no researches of his own the author is dependent entirely upon the work of others, and his philosophic views are coloured by the selection he has made amongst well-known but incompatible theories.

Arbeiten aus der Psychiatrischen Klinik zu Würzburg. Herausgegeben von Privatdozent Dr. MARTIN REICHARDT. Zweiter Heft. S. 94. Jena: Gustav Fischer, 1908.

Contains a paper by Dr. Reichardt in which the fixed pupil is attributed to changes in the cervical spinal cord rather than to disease in higher parts of the nervous system. In another paper the same author suggests that diabetes insipidus may arise as the symptom of mental disease. We must confess that we do not understand either the method of printing or the contents of the first communication in this volume, by Professor Conrad Rieger.

Exposé des Titres et Travaux Scientifiques du Docteur Pierre Marie. Pp. 247 Paris; Masson 1908.

Consists of a summary of the papers written by Professor Marie, together with a list of the cases described by him before various societies. A purely personal record.

Writers of "Original Articles and Clinical Cases" are supplied free of charge with 50 copies reprinted in the form in which the paper stands in the pages of "Brain." If reprints are required in pamphlet form, with wrapper, title-page, &c., and re-numbered pages, they must be ordered, at the expense of the writers, from Messrs. BALE, SONS & DANIELSSON, Ltd., 83-91, Great Titchfield Street, London, W.

Members of the Neurological Section of the Royal Society of Medicine can obtain the Index of "Brain" for the Volumes I. to XXIII. inclusive, that is, from its commencement to the end of 1900, from Messrs. MACMILLAN & CO., Ltd., St. Martin's Street, London, W.C., at the price of 6s. 6d., post free.

To those who are not members of the Neurological Section of the Royal Society of Medicine the price is 8s. 6d. net, and the volume may be obtained through any bookseller.

EDITOR.

[FEBRUARY, 1909.]

BRAIN.

PART IV., 1908.

Original Articles and Clinical Cases.

TWO ANOMALOUS CASES OF SYRINGOMYELIA.

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THE two cases of syringomyelia which form the subject of this paper offer some points of interest from both the pathological and clinical standpoints. In neither of the cases was the disease diagnosed during life, and in both complicating conditions were found in the central nervous system on *post-mortem* examination.

It is now generally admitted that syringomyelia is not a pathological entity, but a condition which may develop either primarily, or more rarely secondary to different pathological processes involving the spinal cord. The difficulty, which has been recognized by Schlesinger and other authorities, in defining syringomyelia in terms of pathology has undoubtedly led to the inclusion of many cases under this name on entirely inadequate grounds. It seems to us, however, that the chief lesions in the cases we report conform so completely to those which characterize syringomyelia that they must be included in this disease, no matter what definition of it be adopted.

CASE I.

Syringomyelia and Syringobulbia associated with Syphilitic Pachymeningitis

J. S., a journalist, aged 43 years, was admitted in September, 1907, to the National Hospital under the care of Dr Ormerod, to whom we are indebted for permission to use the clinical notes. As he was an educated man and took an intelligent interest in his disease it was possible to obtain a full and accurate history of his case.

At the age of 18 he contracted syphilis, and later had well-marked secondary symptoms, including condylomata; he neglected to follow the treatment prescribed. Three years later he developed a double-hemiplegia with optic neuritis; for a fortnight, according to his own account, he was totally paralysed, but recovered quickly under anti-syphilitic treatment. A cerebral gumma was diagnosed. After this he underwent several "cures" at Aix and other places

Thereafter he remained fairly well till four years before his admission to hospital, though for years he had complained of unsteadiness of gait and difficulty in walking in the dark. Within the past four years his gait has become worse, his legs more stiff and rigid, and he has tired very easily. During the past year he has required two sticks to get about at all, owing to the progressive weakness of his legs and the difficulty in balancing himself. For years he has also had difficulty in starting micturition.

For two years he has had diplopia, and his sight has deteriorated. Recently he has noticed ataxia of his arms, he found in using his typewriter that "his fingers would strike the wrong letters"

The patient was under treatment by several physicians, but we are ignorant of the diagnoses which were made; apparently the disease was generally regarded as syphilitic, but by an eminent French neurologist he was told he had "*tabes combinée.*"

On examination smell, taste and hearing were found normal, but vision was reduced to $\frac{6}{18}$, and ophthalmoscopic examination revealed optic neuritis subsiding into consecutive atrophy; the swelling had disappeared, but the edges of the discs were blurred, the physiological pits filled in, and the vessels reduced in size. There was slight internal strabismus and diplopia, and all ocular movements, but especially conjugate lateral deviation, were accompanied by nystagmus. The pupils were small, but regular in outline; their reaction to light was sluggish, but they contracted well on accommodation. The facial muscles and the movements of the tongue and palate were intact, and deglutition, phonation and articulation were unaffected.

The chief symptoms of the disease were seen on examination of the motor system. The muscles of the head and neck were unaffected, and in the upper extremities the muscles were well developed, none were wasted, their tone was good, and the strength of the larger movements was excellent, but the finer movements were ataxic. No local atrophy or paresis was detected in the muscles of the trunk, the patient was able to rise from the prone to the sitting position without the aid of his arms There was no wasting in the lower limbs, but both were very spastic, and their movements were feeble, especially dorsiflexion of the feet. His gait was very spastic and ataxic, the knees were held rigidly extended and the toes dragged along the ground. Romberg's sign was well marked.

Examination of sensation revealed a relative analgesia of considerable degree on the ulnar aspect of both upper extremities, and on the trunk from the level of the second costal cartilages to midway between the xiphoid and the umbilicus. There was also some diminution of tactile sensibility, as tested with cotton-wool, over the same areas, but of considerably less degree than the analgesia. Thermal sensibility, as far as it was tested, was intact. Joint-sense and the appreciation of pain on deep pressure were also normal in all limbs. There was no history of shooting pains or other paræsthesiæ.

The tendon-jerks of the upper extremities were brisk; the knee-jerks and ankle-jerks were much exaggerated; ankle-clonus was easily obtained, and both plantar responses were of the extensor type.

The patient left hospital in a practically unaltered condition; some weeks later he died in an attack of acute pneumonia, and through the courtesy of his medical attendants we were able to obtain a *post-mortem* examination.

The autopsy was performed about eighteen hours after death. The brain appeared but little altered, and there was no evidence of disease on its surface. The soft membranes at the base and on the ventral surfaces of the pons and medulla were opaque and slightly thickened, and the walls of the larger arteries were thickened. Even before cutting open the spinal dura mater it was evident that there was gross disease of the spinal cord; it appeared shrunken and flattened antero-posteriorly. The membranes were also very much thickened, especially in the cervical and upper dorsal regions, and it was in many places impossible to separate the dura mater from the thickened and opaque pia-arachnoid, by which it was bound down to the surface of the cord.

The meningeal disease was greatest over the cervical and upper dorsal segments; in the lumbar and sacral regions it was inconsiderable, though even here the soft membranes were more opaque and more firmly bound down to the cord than normally.

When the cord was cut across, a cavity was seen in its centre extending from the mid-lumbar region to the highest cervical segments. It was largest in the upper dorsal region, and to the naked eye it appeared to extend into the medulla.

Microscopical Examination.

The exact condition of the spinal cord could be determined only by microscopical examination. The nervous system was first hardened in 10 per cent. formalin in normal saline solution; blocks from each segment of the cord and from the medulla oblongata were then prepared for Weigert's medullary sheath stain, and sections from each of these blocks were also stained by hæmatoxylin and van Gieson's method. Sections of other blocks from various regions were stained by Mallory's method for the demonstration of neuroglia.

The Meninges.—The thickening of the meninges becomes well marked at the level of the decussation of the pyramids, and is very intense over the cervical enlargement. It lessens slightly over the upper dorsal segments, and increases again in the middle and lower dorsal regions, but finally disappears at about the level of the third lumbar segment. Over the lower two lumbar segments and the sacral cord there is practically no thickening of the meninges, but some small round cell infiltration persists similar to that to be described in the higher levels. The thickened meninges are densely sclerosed; where the thickening is most intense, calcareous concretions and layers of bone lie in them. In places, as in the ventral surface of section shown (fig. 2), it was necessary to cut away the bone before preparing the section.

The dura mater, as well as the pia-arachnoid, is involved in the thickening, and firmly bound to it by adhesions. The thickened pia mater is also abnormally adherent to the surface of the cord. The majority of the meningeal vessels are diseased; their walls are thickened and frequently hyaline: in other vessels there is considerable proliferation of the intima, but this change is less common. Further, around many of the vessels, as well as in the less compact portions of the thickened membranes, there are foci of small round cell infiltration, and in places among these cells typical plasma-cells. As already mentioned, the cellular infiltration extends over the lumbar cord where there is little or no thickening of the meninges; the same condition may be observed in the medulla. In many places there is marked perivascular infiltration around the intramedullary vessels of the cord and brain-stem.

Spinal Cord.—The topography of the intramedullary disease is most easily traced in Weigert preparations, but at each level its histology was also studied in sections stained by hæmotaxylin and picro-fuchsin, and in many segments in Mallory preparations as well.

In the sacral and lower lumbar segments, the only disease is secondary degeneration of the crossed pyramidal tracts. The definite syringomyelic disease appears in L_4 segment as a dense gliosis in the grey commissure and the base of the left dorsal horn, which in the next higher segment becomes much more extensive and produces a considerable increase in size of the left side of the cord. The disease is most prominent in the dorsal horn and the neighbouring part of the dorsal column; in the periphery of the dense glial tissue many Deiters's spider-cells with long branching processes can be seen, while the centre has undergone partial rarefaction, but as yet there is no sharply defined cavity. In Mallory preparations the glial tissue appears much more extensive than in sections stained by other methods, it extends across the grey commissures and into the base of the right dorsal horn.

In the L_1 and L_2 segments a large cavity occupies the grey commissure, the ventral portion of the dorsal column and practically the whole of the left dorsal horn, and an evagination from it extends into the left lateral column. Its walls are composed of dense neuroglial tissue with many spider-cells; they contain many blood-vessels, the walls of which are as a rule thickened, and some of them are hyaline. The gliosis is much more extensive than the cavity; it extends along the dorsal median septum, and across the commissure into the right dorsal horn, in the centre of which there is some rarefaction. The ventral horns are intact at this level, but there is intense degeneration in the lateral column in the position of the pyramidal tracts. In the lowest two dorsal segments the disease is similar in nature and extent.

In D_{10} the cavity is considerably larger; it occupies almost the whole of each dorsal horn, and extends between them through the grey commissure, involving also the ventral half of the dorsal column; it lies entirely dorsal to the central canal, which is represented by a solid column of ependymal cells. On the right side a projection of the cavity extends into the lateral column, and on the left a separate but smaller cavity lies in the inner portion of the lateral column, parallel to the lateral border of the dorsal horn. As a rule the walls of the cavity consist of a densely sclerosed neuroglia, but in places the tissue is less compact, and coarse glial fibrils and vessels with thickened walls project into its lumen. The ventral half of the dorsal column, and the dorsal and inner portions of each lateral column, are invaded by the sclerotic gliosis which surrounds the cavity; where the gliosis is advanced, practically no myelinated fibres can be found. About this level the thickening of the meninges becomes more prominent, and secondary thereto there appears some degeneration in the periphery of the white columns; this persists through all the higher segments of the cord, being most pronounced on its ventro-lateral surface. Further, a partial degeneration of the spino-cerebellar tracts commences at this level.

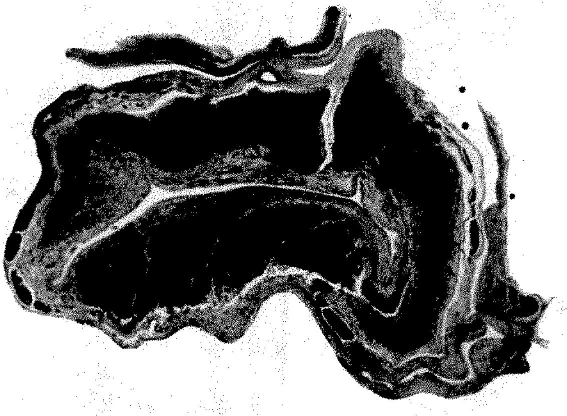

FIG. 1.

Section of the fourth dorsal segment; owing to collapse of the cavity the cord appears much deformed. There was considerable meningitis around the cord; part of the meninges had been cut away.

In D_6, D_7, D_8, and D_9, there is little change; a large cavity, which sends branches into each lateral column, extends from the extremity of the one dorsal horn into that of the other. The gliosis around it reaches the periphery of the cord at, and lateral to, the entry of the dorsal roots. The meninges are very much thickened, and the peripheral degeneration of the ventro-lateral columns is well marked. The central canal is represented by an irregular row of ependymal cells in the ventral wall of the cavity.

The extent of the cavity in D_4 is represented in fig. 1; the fifth segment is very similarly affected. Here the walls of the cavity consist mostly of dense sclerotic tissue, giving a fairly smooth surface to its lumen.

In the upper three dorsal segments the disease is perhaps more extensive than in any other region of the cord. As in the segments which have been described, it occupies almost the whole of each dorsal horn and a considerable part of the dorsal column; part of each lateral column is also involved. The cavity wall consists of dense glial tissue with few nuclei, but in places irregular nodules or tongue-like projections of densely sclerosed tissue containing large numbers of round darkly staining nuclei jut into the cavity; these are often very rich in blood-vessels, the walls of which are frequently thickened and hyaline. The less compact glial tissue, on the other hand, contains larger nuclei, which are granular and stain less deeply. Many of these seem to belong to Deiters's cells.

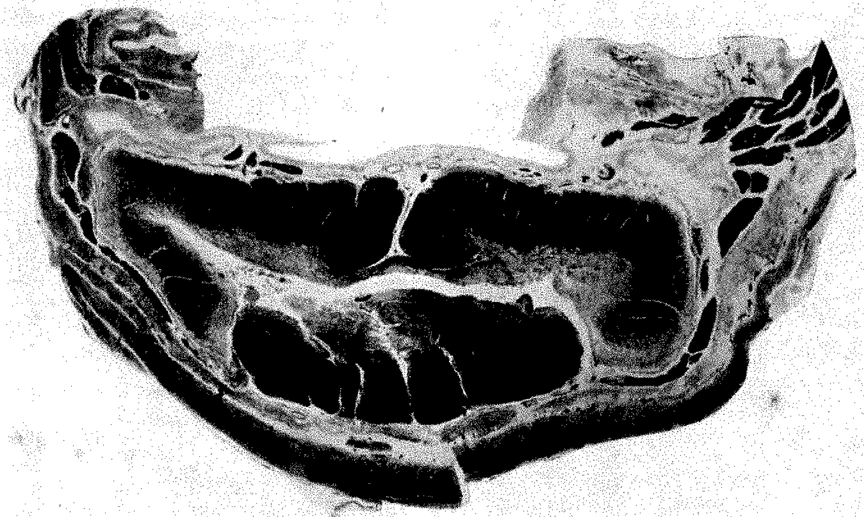

FIG. 2.

Section of the fifth cervical segment. The thickened meninges had to be cut away on the ventral surface of the cord before the section was prepared, owing to the presence of bone in them.

The surrounding gliosis in each segment extends a considerable distance dorsalward along the dorsal septum, so that in Weigert sections a pale triangular area with base ventralward occupies the centre of the dorsal columns. In the lateral column the gliosis involves the inner portions of the pyramidal tracts, and extends along the dorsal horns to include part of Lissauer's zone. In the second dorsal segment, part of the ventral wall of the cavity is lined by ependymal cells, but in the neighbouring segments the central canal, represented by a column of cells, is separated from the cavity, as in every other segment there is considerable gliosis around it.

In the lower two cervical segments there are two separate cavities, one in each dorsal horn. They are separated by the gliotic tissue which surrounds the central canal. The gliosis at this level extends into the dorsal column and a short distance into each ventral horn; the latter appear somewhat rarefied.

In C_5 the cavity in each dorsal horn again communicates with its fellow across the commissure and the ventral portion of the dorsal column (fig. 2). On the left it passes beyond the grey matter into the lateral column. The ventral horn, though flattened out, contains an almost normal number of large cells. Even at this level the crossed pyramidal tracts are severely degenerated, and there is a considerable degeneration of the dorsal and ventral spino-cerebellar tracts, as well as slight degeneration of the periphery of the ventral columns.

The dorsal part of the dorsal columns is relatively little affected, but there is marked degeneration of their ventral two-thirds, partly ascending system degeneration, partly the result of their invasion by the gliosis. At this level the fibrosis and thickening of the meninges is extreme.

The nature and extent of the disease is almost unchanged in the upper three cervical segments. In each the single cavity which involves the whole of the dorsal horns and the grey commissure sends a large evagination lateralwards into each ventro-lateral column in the plane of the commissure; on the left this almost reaches the periphery of the cord, and on the right more than half-way across the white column. The gliosis that surrounds the cavity is extensive, especially in the ventral part of the dorsal columns. The degeneration of the pyramidal tracts is much less than in the lower segments, and almost disappears towards their decussation. The degeneration of the spino-cerebellar tracts remains distinct, and there is considerable sclerosis of Goll's columns and some irregular degeneration in Burdach's.

At the decussation of the pyramids a large amount of dense gliotic tissue surrounds the central canal and extends dorsalwards on either side of the dorso-median fissure, forming in Weigert sections a pale pyramid with its base ventralward and its apex on the dorsal periphery. The syringal disease is here represented by slit-like cavities which extend almost directly lateralwards to the periphery of the cord at the ventral margin of the substantia gelatinosa Rolandi. There is relatively little gliosis around these cavities. Projections from the central gliosis also extend between the gracilis and cuneate nuclei; each is somewhat rarefied in its centre, but the rarefaction has not advanced to cavity formation.

In higher sections the pathological changes alter but little. At the level of the fillet decussation an excess of sclerotic neuroglia still surrounds the central canal, which has not yet opened out; and from its dorsal portion two slit-like cavities extend ventro-lateralwards towards the ventral margin of the spinal fifth root, running parallel, but slightly ventral, to the outgoing vagus roots. This, with the ascending degeneration of the spino-cerebellar tracts, is the only disease at this level.

The disease remains practically unchanged after the central canal has opened out into the fourth ventricle (fig. 3). The irregular nodules which were visible to the naked eye along the median furrow of the lower end of the ventricle were found to be due to a proliferative gliosis of this region. From here slit-like cavities run, as in the sections just described, towards the spinal fifth root, but they do not reach further than half the distance to the periphery: the internal arcuate fibres bend round the lateral margin of each cavity, and each fasciculus solitarius lies dorso-lateral to it and seems but little affected by it. The disease ceases completely in about the upper third of the medulla oblongata.

Examination of the forebrain revealed no important changes, excepting hydrocephalic dilatation of the lateral ventricles. The foramina of Munro were patent and the aqueduct of Sylvius was much dilated, evidently a result of the internal hydrocephalus. Microscopical examination of the walls of the aqueduct revealed an interesting condition, as in many places its ependymal lining was absent, and here and there a considerable amount of tissue was eroded away or torn through by the distension; at the level of the third nuclei this change extended so deep that the dorso-lateral margin of the nucleus on one side was involved in the secondary gliosis. The view that the rupture of the ependymal lining was due only to mechanical causes is supported by the fact that the ependymal cells which persist are much flattened. The hydrocephalus probably resulted from occlusion of the foramen of Majendie by the meningitis, but as the membranes were unfortunately torn here in removing

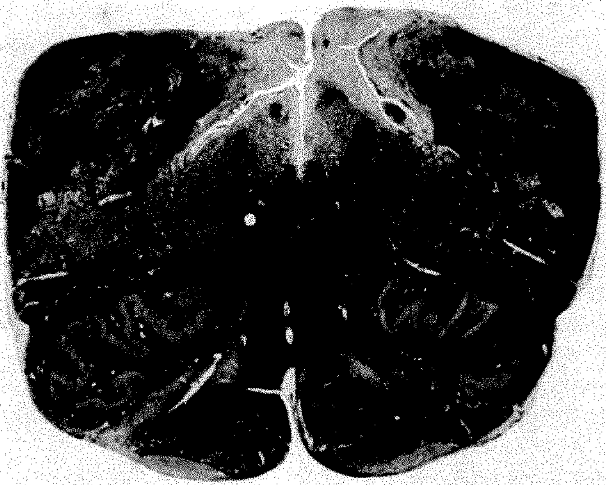

FIG. 3.

Section of the lower end of the medulla showing the gliosis around the calamus scriptorius, and the cavities extending from it ventro-lateralwards.

the brain it cannot be with certainty asserted that the foramen was completely blocked.

Some of the clinical and anatomical features of this case seem worthy of discussion. The condition which was found on *post-mortem* examination of the nervous system may be dealt with first.

Of the nature of the spinal pachymeningitis there can be scarcely any doubt. In addition to the very definite history of syphilitic infection and of its sequelæ, and of the improvement of some of the symptoms under antisyphilitic treatment, the view that the meningitis was syphilitic was confirmed by the histological changes which we found, *i.e.*, the intimal disease of many of the vessels in the meninges and throughout the nervous system; the hyaline degeneration of the walls of others; and, finally, the presence of perivascular infiltration by small round cells and by plasma-cells. Although the meningitis was most extensive on the spinal cord there was also some on the basal surface of the brain-stem.

On the other hand, there can be no doubt but that the gliosis and the cavity in the cord and the medulla oblongata correspond with the condition which is characteristic of syringomyelia. The cavity occupies the region which is typically occupied by syringomyelia, and the distribution of the disease in the bulb is so characteristic of syringobulbia that there can be no hesitation in including the case in this class. Further, the glial walls of the cavity and its relation to the central canal conform to the changes of syringomyelia.

The nature and the significance of the association of these two processes, the meningeal and the syringomyelic, is extremely interesting and very important in relation to the pathogenesis of syringomyelia. This association is not infrequent; it has been long recognized, but it is not our intention to attempt to review the literature on the subject here; this has been recently done by Rhein [11], who succeeded in collecting thirty-five cases, and added one of personal observation.

The occurrence of a thickening of the meninges, and especially of the pia mater, is often observed over spinal cords in which there has been extensive parenchymatous degeneration, the meningeal being secondary to the medullary disease, but independent of its etiology. That such secondary thickening of the membranes may occur in a cord which has been severely or for long involved by syringomyelia is not surprising, but such cases must be excluded from consideration here. There remain, however, a considerable number in which the association of the two conditions can be explained only by the assumption of a coincidence, or of a common etiological factor, or by regarding the syringal disease as secondary to the meningeal.

The proportion of cases of syringomyelia in which a meningitis occurs is so considerable that it is scarcely possible to assume a mere coincidence. But before attempting to decide on the other alternatives it is necessary to determine, as far as possible, the nature of the meningeal changes which occur in these cases.

In a certain number, as in the cases reported by Phillipe and Oberthür [9], by Müller and Meder [8], and by others, there was only a fibrotic thickening of the meninges without changes specific of any cause; in one recorded by Zenoni [18] it was regarded as tuberculous, and in one of Saxer's cases [13] it was a sequel to acute cerebrospinal meningitis. In a larger series of cases—as in those reported by Japha [6], Schwarz [15], F. Taylor [16], Rhein [11], and in our own—there could be scarcely any question of the syphilitic nature of the pachymeningitis. In Japha's case there was a diffuse gummatous meningitis, and in Taylor's a gumma was found in the spinal dura. The conclusion must be, therefore, accepted that the pachymeningitis occasionally associated with syringomyelia is not always of the same nature.

Against the first alternative, that the spinal and meningeal changes are due to a common cause, it must be urged that the latter are undoubtedly rare in syringomyelia. According to Schlesinger [14] the membranes are quite unaffected in the majority of the cases. On the other hand, a considerable proportion of the cases of syringomyelic pachymeningitis have been syphilitic, and there is certainly little ground for the view that any form of syringomyelia, apart from that associated with such meningitis, is due to syphilis, which it would be necessary to assume if the association of the two conditions is to be ascribed to a common cause.

It seems more probable that the spinal disease is secondary to the meningitis, and due in some way to compression of the cord or interference with its blood or lymph circulation. In favour of this is the fact that when the cord is compressed, or the spinal circulation disturbed, softening is more liable to occur in the region which syringomyelia generally involves—that is in the base of the dorsal horns and the adjacent part of the commissure—than in any other area. It is, however, difficult to determine the exact mode of origin of the cavities and of the gliosis which surrounds them. That a cavity may arise directly by necrosis and absorption of tissue secondary to anæmia and lymph stasis, and become later surrounded by sclerosed neuroglia, is certain; it is occasionally observed with compression paraplegia or associated with a myelitis, but it is very doubtful if an extensive and regular cavity, such as was present in our case, can originate in this way. A process similar to that described by Schwarz [15] is more likely; the circulatory disturbances excite a primary change in the neuroglia, which proliferates and later assumes a homogeneous appearance with faintly staining properties, owing to degenerative changes or a transudation into it; or the neuroglial changes may be degenerative from the onset. Cavities arise secondarily by rarefaction of these areas, and their walls may remain composed of rarefied or reticular tissue, or become sclerosed.

This view is the more interesting, as it brings the pathology of these cases into line with that of primary idiopathic syringomyelia, in which it is generally believed that a gliosis, or other change in the neuroglia, precedes the cavity formation. Further, the disturbance of circulation and the lymph stasis which excite or produce the glial lesions have been recognized as causal agents, combined with a central gliosis which may be due to a developmental anomaly, in ordinary syringomyelia; Schlesinger attributes great importance to the vascular changes which are almost constantly found in the spinal cord in this disease.

There are, however, difficulties in accepting the view that in such cases the meningeal lesions are the sole agent in the production of the syringomyelic changes; there is the fact that in our case the cavity formation was not in any way parallel to the degree of meningitis. In the bulb, for instance, the lesions, which were typical of ordinary syringomyelia, were associated with only a very slight amount of local meningitis or vascular disease. In the cases of Rhein and Saxer, in which there was also syringobulbia, there was more meningitis about the medulla.

On the whole it is most reasonable to accept the view which has been repeatedly advanced that the condition we call syringomyelia is not always of the same nature or due to the same cause, and to conclude with Schlesinger that there is a sub-variety which is the result of meningeal and vascular disease, and unlike the more common form is independent of developmental anomalies. Though the existence of this sub-variety be admitted it seems impossible to associate it at present with any definite group of symptoms. Our own case as well as Taylor's and others show that it is not always, as Rhein states, "characterized clinically by the presence of sharp pains in the distribution of the nerves and other subjective sensory phenomena."

The existence of an internal hydrocephalus was another point of interest in our case; to its onset, or perhaps to an acute exacerbation in its course, the paralysis of the limbs and the symptoms of increase of intracranial pressure of which the patient gave such a definite history were doubtlessly due. The co-existence of hydrocephalus with syringomyelia is not exceptional; Hinsdale [4], in searching through the literature, found mention of this condition in 15 out of 150 cases of syringomyelia. In some of these the hydrocephalus was apparently idiopathic, or more correctly its cause could not be ascertained; in our case and in others the existence of a diffuse meningitis may explain its origin. The extraordinary dilatation of the aqueduct of Sylvius indicated that the obstruction must have existed at or behind the foramen of Majendie.

Optic neuritis, such as existed in our case, has also been observed, but only very rarely, with syringomyelia. In a case reported by Saxer [13] the diagnosis was confirmed by autopsy. There was a cavity in the cervical cord, which was also much enlarged, and some hydrocephalus. To the latter condition the optic neuritis was undoubtedly directly due, while it probably resulted from blocking of the flow of cerebro-spinal fluid by the enlarged cord. It was thus that Taylor and Collier [17] have explained the occasional association of optic neuritis with tumours and myelitis in this region of the cord. Bullard and Thomas [1] also found optic neuritis associated with syringomyelia in a boy, aged 6½; in this case, too, there was considerable hydrocephalus. The diagnosis in Weisenberg and Thorington's case [18] was not confirmed by autopsy.

CASE II.

Syringomyelia without Symptoms, Associated with Intracranial and Spinal Tumours.

A. N., aged 46, was admitted to the National Hospital in July, 1905, under the care of Sir William Gowers, to whom we owe our thanks for permission to report the case.

He complained of headache and gradual loss of sight, and according to his history he had been subject to general epileptiform fits at long intervals for the preceding seventeen years. For some months he had also had true "dreamy states" unassociated with convulsive attacks.

On examination the optic discs were found in post-neuritic atrophy, with corresponding loss of vision. Beyond slight paresis of the left external rectus there was no abnormality of the ocular movements, excepting nystagmus on conjugate deviation to the right; the other cranial nerves were unaffected.

All movements of the head and neck were natural, and in the upper extremities nothing abnormal was found beyond slight tremor of the hands when held outstretched ; there was no weakness, wasting, spasticity, or ataxia. The muscles of the thorax, spine and abdomen also contracted well and equally on the two sides. All movements of the lower limbs were well performed; there was no spasticity, wasting or ataxia, and gait was perfectly normal. No unsteadiness was observed when the patient closed his eyes and stood upright with his feet together.

On testing sensation it was found that the appreciation of pin-pricks and of cotton-wool touches was everywhere acute, and the discrimination of temperature was everywhere accurate. There was no astereognosis or atopognosis.

The deep reflexes were diminished in both the upper and lower limbs, and the abdominal and epigastric reflexes were not obtained ; the abdomen, however, was flabby and pendulous, a fact sufficient to account for their absence. The plantar reflexes were invariably of the flexor type on both sides. At no time was there any affection of the sphincters, beyond a slight delay in starting micturition.

About a week after admission a tumour which had been diagnosed in the right tempero-sphenoidal lobe was removed by Sir Victor Horsley; it was circumscribed and of oval shape, measuring 6 × 4 cm. The patient, however, died in an attack of respiratory failure some time after the operation.

At the *post-mortem* examination it was found that the tumour which had been removed had grown from the dura mater of the anterior part of the middle fossa of the skull. Another tumour of almost equal size lay imbedded in the tip of the left frontal lobe ; while several smaller nodules of growth, of the same firm consistence, were attached to the dura mater covering the surface of the hemispheres, and particularly to the falx cerebri and tentorium cerebelli. To the naked eye all tumours were similar in structure; all undoubtedly took origin from the dura mater and compressed, but did not invade the brain, being everywhere separated from it by the pia-arachnoid, which was stretched out unbroken over their surfaces.

Histologically, all these tumours were identical in nature and conformed to the structure of the psammomata. They were rich in nuclei, but very little cytoplasm could be distinguished around them ; the nuclei were generally spindle or oval in shape. Throughout large areas the cells were arranged irregularly, but much of the tumour consisted of cells arranged in concentric whorls. Following the development of these whorls, it may be seen that as they increase in size the cells, and particularly those of the inner layers, become flattened concentrically. The next stage in their evolution is apparently hyaline degeneration, which commences in the centre, so that we have a core which is structureless, or perhaps contains the badly staining remnants of nuclei, surrounded by cells which are as yet intact.

Occasionally two or more whorls become enclosed in a common sheath of flattened endothelial cells, which later may also undergo hyaline degeneration. After the development of this retrograde change calcareous granules are often deposited in the hyaline centres of the whorls ; these may gradually accumulate and form homogeneous calcareous masses, which either lie free in the tissue of the tumour, or remain enclosed in a capsule of flattened cells. The vessels of the tumour have well-formed walls, but a few of them are in the earlier stages of hyaline degeneration.

The structure of these tumours, though not directly connected with our subject, is given in detail, as it is important to recognize clearly that both in structure and nature they are entirely distinct from that which will be later described in the spinal cord.

No part of the brain-stem was compressed by any of these tumours, and none were found in the spinal dura mater.

The membranes of the cord were normal. When removed, the spinal cord appeared natural from the bulb to the fourth dorsal segment; at this level it increased considerably in size, and then remained fairly uniform in diameter to the level of the eighth dorsal roots. The ninth and tenth segments were much more enlarged, but in the last dorsal segment the size diminished again rather abruptly to the normal. The lumbar and sacral segments appeared unaffected to the naked eye.

After hardening in formalin blocks from each segment were prepared for the Weigert method; sections from each of these blocks were also stained with hæmotoxylin and picro-fuchsin; from a few levels pieces of tissue were taken for Weigert's neuroglia stain.

The topography of the disease is most easily studied in the Weigert sections: in these, as in van Gieson's preparations, no disease is visible in the upper seven cervical segments. In the eighth cervical segment, however, dense fibrillar neuroglia appears round the central canal, and extends into the dorsal columns along the dorsal septum, and into the base of each dorsal horn; in the latter there is some rarefaction of the tissue, but as yet no definite cavity formation.

In the first dorsal segment, similar sclerosed neuroglia surrounds the central canal, which is here dilated into a tube of considerable lumen, completely lined by ependymal cells. A certain amount of sclerosis still extends into the dorsal columns, along the dorsal septum.

In the second dorsal segment the changes are similar, but in places the ependymal lining has been broken through, and coarse thick neuroglial fibrils encroach on the lumen of the central canal.

In the third dorsal segment the central canal is still more distended, and has a less complete lining of ependyma. Here a second cavity appears in the middle of the right dorsal horn: it is irregular in shape, and is limited only by loose reticular but sclerosed neuroglia, which stretches a considerable distance from its edges. From a study of the sections stained by different methods it seems certain that the cavity has arisen by rarefaction of a pre-existing gliosis.

In the fourth dorsal segment the disease is more fully developed; a large cavity, very irregular in shape, occupies the whole of the right dorsal horn and the greater part of the grey commissure. A second cavity, which is evidently continuous with the dilated central canal, lies to its left and near the base of the left dorsal horn; its wall is formed by irregularly proliferated ependymal cells, while the larger cavity is lined by sclerosed neuroglia alone [fig. 4]. Both are enclosed in a common mass of dense neuroglia, which also invades the ventral portion of the dorsal columns, especially along the dorsal septum.

The cavity in the right dorsal horn is still larger in D_5, while the central canal is almost obliterated; its lumen is lined by a single layer of typical ependymal cells; other ependymal cells form a solid column along its ventral margin, and infiltrate the sclerosed glia.

In D_6 a mass of dense neuroglia occupies almost exactly the position in which in the section above lay the larger cavity; this is here represented only by a narrow slit, while the central canal is marked by an irregular column of ependymal cells, such as is found in many normal cords.

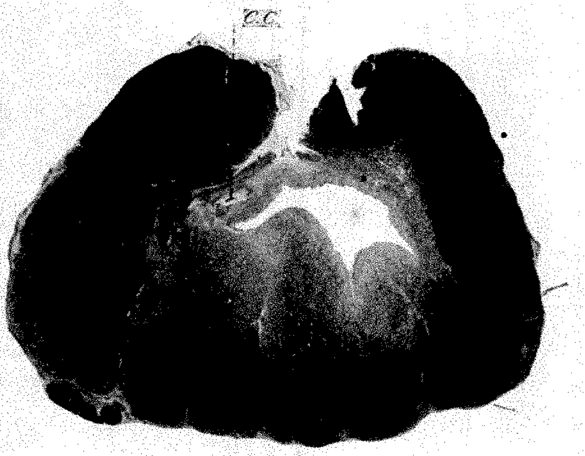

FIG. 4.

Photograph of a section of the fourth dorsal segment stained by Weigert's method; *c.c.* is the central canal.

In the seventh dorsal segment two irregular cavities lie within the mass of sclerosed neuroglia in the right dorsal horn and the neighbouring part of the commissure (fig. 5). The central canal is displaced to the left, but still lies ventral to the gliosis. The cavity ceases between the seventh and eighth dorsal segments, and in the upper part of the latter there appears the large central tumour which was visible to the naked eye. To establish the relationship between the two it is necessary to study serial sections of this region. At the upper level of the change we find first a considerable proliferation of the ependymal cells of the central canal. These form a solid mass which lies at first ventral and to the left of the gliosis and its cavity, but gradually becoming larger spreads along the inner part of the left dorsal horn, so that it comes to lie to the left of the syringal disease. In serial sections it may be easily seen

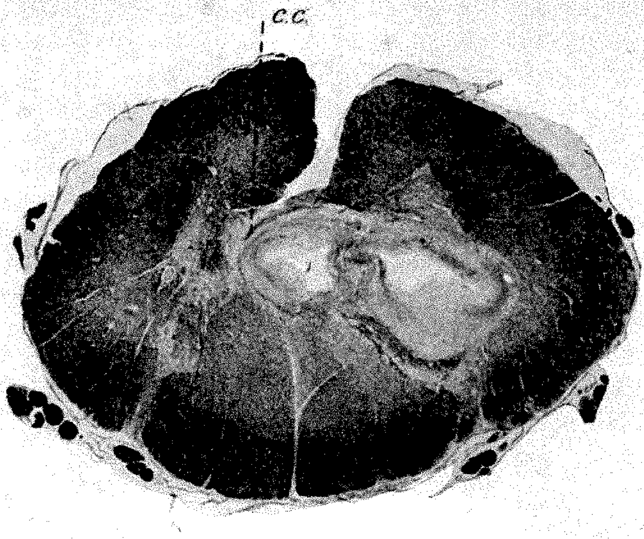

FIG. 5.

Photograph of the seventh dorsal segment; *c.c.* indicates the position of the central canal.

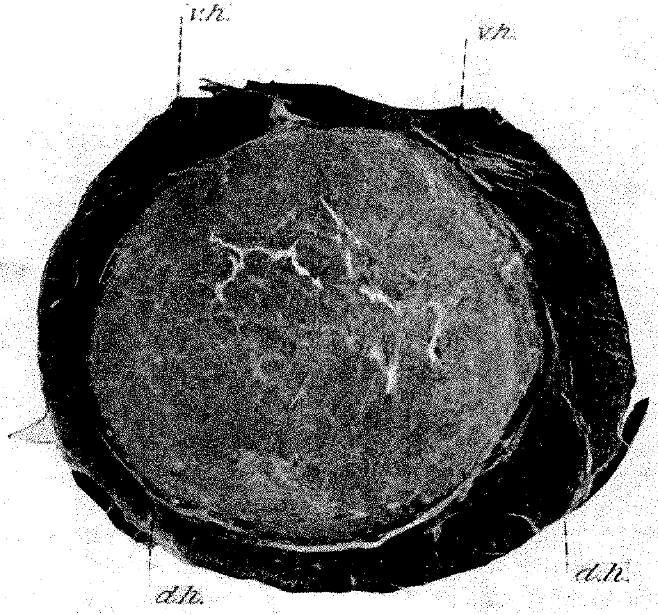

FIG. 6.

A section of the middle of the ninth dorsal segment stained by Weigert's method; *v.h.* the ventral horns; *d.h.* the dorsal horns. The unstained mass in the centre of the cord is the tumour.

that the tumour arises in connexion with, or evidently from, the ependymal cells of this irregular representative of the central canal. It increases very rapidly in size, and in the middle of D_8 it occupies the whole of the centre of the cross-section of the cord; in lateral diameter it here measures about 10·5 mm. and 9·75 mm. in dorso-ventral diameter, while its cross-section is approximately 78 s.mm., that of the whole enlarged cord being 132 s.mm. As the tumour enlarges the syringal cavity and gliosis disappear; in the middle of this segment no trace of them is visible, while the tumour, which is almost circular in cross-section, is surrounded by an almost regular layer of nervous tissue, varying from 1 mm. to 2 mm. in thickness, uninfiltrated and apparently normal in Weigert preparations. In D_9 the tumour is still larger (fig. 7); its area in cross-section is about 113 s.mm., while that of the whole cord is 154 s.mm. The zone of normal tissue that surrounds it is narrower than in the section above, but the tumour nowhere comes to the surface. The ventral horns, which are very much flattened out by it, are the only parts of the grey matter that can be easily recognized; the dorsal horns can be located only by the entry of the dorsal roots. The tumour ends rather abruptly in about the middle of the D_{10} segment. Below the next segment there is no visible disease, and despite the extent and intensity of the focal lesions which have been just described there is no descending secondary degeneration of the pyramidal tracts or of any of the other systems of the lumbo-sacral cord. There was also no trace of ascending degeneration recognizable by the ordinary methods in the upper cervical segments.

The walls of the large syringal cavity are nowhere lined by ependyma; they consist only of gliotic tissue of variable density, in which the glial strands or fibres are irregularly arranged without any trace of membrane-like formation. Where it is less dense the gliotic tissue appears reticular, and consists of irregularly interwoven thick glial fibres, which branch and anastomose with one another. Where denser it has often a gelatinous appearance under a low magnification. The gliosis contains a considerable number of Deiters's spider-cells; the terminal portions of their processes may be often seen to become continuous with the glial fibres. The gliotic tissue has, as a rule, very few nuclei, especially towards the edge of the cavity; here the tissue appears to be undergoing rarefaction at a very slow rate. It is more dense as well as more rich in nuclei in its outer portions; it is not, however, anywhere sharply limited from the normal spinal tissue, into which dense glial strands penetrate irregularly.

The relation of the central canal to the syringomyelic cavity, and more especially to tumour, must be accurately described. In the upper cervical segments the canal is represented, as is usual in the adult, by a solid column of ependymal cells. In C_8 it becomes patent, and is completely lined by a layer of ciliated ependymal cells. In the first and second dorsal segments its lumen is considerably larger, and is still lined, or almost completely lined, by ependyma. Here there is a typical hydromyelia. As the syringal cavity develops, the lumen becomes smaller, and the canal is compressed and displaced towards the base of the left ventral horn. In D_6 and D_7 the canal is again represented only by a column of ependymal cells, which are much more numerous than normal, but it still lies in the typical way ventral to the gliosis. In the upper part of D_8 the proliferated ependymal cells begin to form a definite tumour-like mass, which spreads at first dorsalwards into the dorsal column and the neighbouring portion of the dorsal horn, and finally comes to occupy practically the whole of the centre of the cord in the eighth, ninth, and tenth dorsal segments (fig. 7).

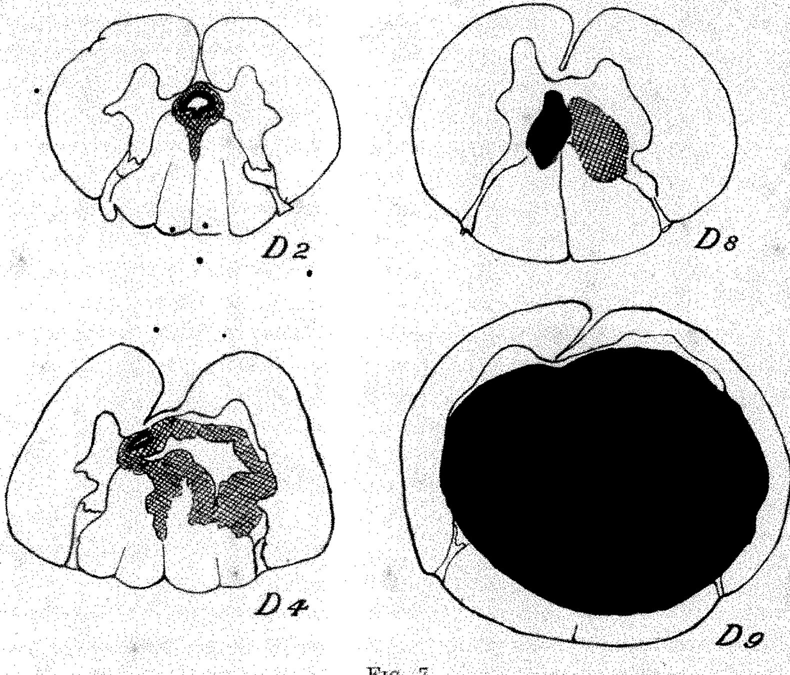

FIG. 7.

Drawings to show the relation of the central canal and its ependymal cells to the spinal tumour and to the syringomyelia. Ependyma black, the syringal gliosis cross-hatched.

The structure of the spinal tumour is simple; although it does not infiltrate the spinal tissue that surrounds it, it is not sharply limited from it by any capsule or membrane. It is composed of very irregularly arranged strands of fibrillar tissue, in which there lie large numbers of fairly large nuclei, oval when cut in length, round when cut in cross-section; but in many places, and especially around the vessels, there is a complete absence of such nuclei. They stain rather deeply and contain coarse chromatin granules. The fibrillar tissue has the structure and staining reactions of sclerosed glia, and along the margins of the tumour its strands run into and fuse with the neuroglia of the normal spinal tissue. The vessel walls are well formed, but many are thickened, and some are hyaline. At the lower end of the tumour there is an excess of vessels. In places in the outer portions of the tumour a considerable amount of cytoplasm collects around some of the nuclei, and often runs out into irregular branching processes, which may or may not be connected with the fibrils of the stroma of the tumour. There is no visible degeneration, and remarkably little evidence of reaction or sclerosis in the nervous tissue around the tumour, despite the compression to which it had been subjected. The tumour apparently started in the centre of the cord and slowly displaced, but did not destroy, the tissue in which it grew.

Histologically, the tumour is undoubtedly a glioma which has arisen from the ependymal cells of the central canal, but there is nowhere a tendency to a glandular arrangement of the cells, such as Rosenthal [12] has described in a somewhat similar case.

It is our intention to limit our remarks on this case, which is as remarkable from the clinical as from the pathological point of view, to as small a compass as possible.

In the cord were found two conditions, distinct from, though possibly related to, one another.

The extensive primary gliosis in the dorsal horns, the grey commissure and the neighbouring portions of the dorsal columns, with the cavity formation within it, is typical of syringomyelia. On the other hand, the large tumour which lay in the lower dorsal segments was undoubtedly a glioma, which apparently grew from the ependymal cells of the central canal, these having assumed the *rôle* of glioblasts.

It is difficult to say how far the syringomyelic lesions were dependent upon the existence of this tumour. We may, in the first place, exclude the possibility that that cavity has arisen by softening and disintegration of portions of this tumour which had previously extended through the upper and middle dorsal segments; this process, it is well known, occurs in spinal gliomata and produces extensive intramedullary cavities, but in our case the structure of the tumour is entirely distinct from the gliosis which surrounded the cavity; and there is no evidence of the previous existence of such a tumour in the upper dorsal segments. Finally, where the two conditions co-exist, as in the upper portions of D_8, they remain anatomically distinct.

On the other hand, it must be remembered that intramedullary cavities not infrequently arise in connexion with spinal tumours, or even secondary to compression of the cord. It appears improbable, however, that in this case the tumour was an etiological factor in the development of the syringomyelia, more particularly as from its structure it appears to be more recent than the gliosis which surrounds the cavity.

More probably both conditions arose independently of one another, though possibly dependent upon a common developmental anomaly; the existence of tumours in other tissues, as in the cerebral dura mater, makes it probable that there was some inherent bioplastic anomaly in the central nervous system and its membranes.

The association of the syringomyelia with the cerebral tumours is probably to be explained by the same assumption—that both were dependent on developmental anomalies. It is, however, of interest to note that the association has been not infrequently observed. In the cases reported by Gowers [2] and by Harris [3] there were, in addition to sarcomatous tumours in the pons Varolii, secondary deposits within the spinal theca; owing to this complication these cases need not be further considered.

Langhans [7], however, found in three cases in which tumours lay in the region of the fourth ventricle cavities in the cervical and dorsal segments of the cord, which, though in places connected with the central canal, were probably syringomyelic. In these cases there were no secondary deposits in the cord, and as one tumour was a melanotic sarcoma, and the other two sarcomata, they could scarcely have been directly related to the cavity formation. According to Langhans, the latter resulted from the blood-stasis in the cord which was produced by the compression of the spinal veins as they enter the skull through the foramen magnum.

Pick and Schultze [10], however, found syringomyelia associated with a tumour of the corpus callosum, and Homén [5] with one in the tempero-sphenoidal lobe. In the majority of the recorded cases the tumours have been gliomata, as might be expected since these are the most frequent of all cerebral tumours; but tumours of other nature, as in our own case, have also been found.

From the clinical point of view the complete absence of all symptoms and physical signs pointing to a spinal lesion is remarkable; and this despite the fact that, owing to the difficulty in the accurate localization of the intracranial disease, the patient was repeatedly examined with all possible care. It is impossible to offer a full explanation of this fact, but it may be again pointed out that the spinal tumour displaced and compressed the spinal tissue rather than destroyed it.

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A CASE OF HÆMORRHAGIC MYELITIS.

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THE following case is remarkable for the slight changes found in the central nervous system after death, in comparison with the severe symptoms present during life, and which led directly to a fatal termination:—

Mrs. F., aged 46, had always enjoyed good health, except for an attack of scarlet fever, followed by nephritis, eighteen years previously. The nephritis was completely cured after two years. At the beginning of March, 1907, she helped to nurse a friend who was suffering from a rapidly fatal attack of acute lymphatic leukæmia; the nursing involved night-work and a good deal of lifting. After a few days she felt very tired, and on the evening of March 8 she was suddenly seized with palpitation, a sensation of constriction in the chest, and loss of power in the arms and legs, so that she had to sit down and support her head and shoulders on the table. After a short time she recovered and sat up that night with her patient, although her legs felt heavy and weak. She went on fairly well until March 10, when, after a good night in bed, she had an attack of general trembling. She got up, however, but on sitting down to breakfast she suddenly lost all power in her limbs and back, the muscles being flaccid and helpless; she would have fallen from her chair, but was caught and lifted into a large easy chair. The arms felt as if tied to the body, both arms and legs were powerless, and she could feel nothing on the trunk or limbs below the neck. Evidence of vasomotor disturbance was present in the form of extreme pallor of arms and hands, and of flushing of the face. Two or three hours later she was able to move her arms, and felt "pins and needles" in arms and legs. Later severe pain appeared along the left lower costal margin, and during the next few days she suffered also from shooting pains in the limbs and trunk.

There was no loss of consciousness in either of the initial attacks, and no pain. The pulse during the second attack fell to 40, and remained at this rate until March 11, when three attacks of palpitation occurred, in which the pulse rose to 110. On this day also obstinate vomiting set in and lasted for three days. There was no affection of the bladder or rectum.

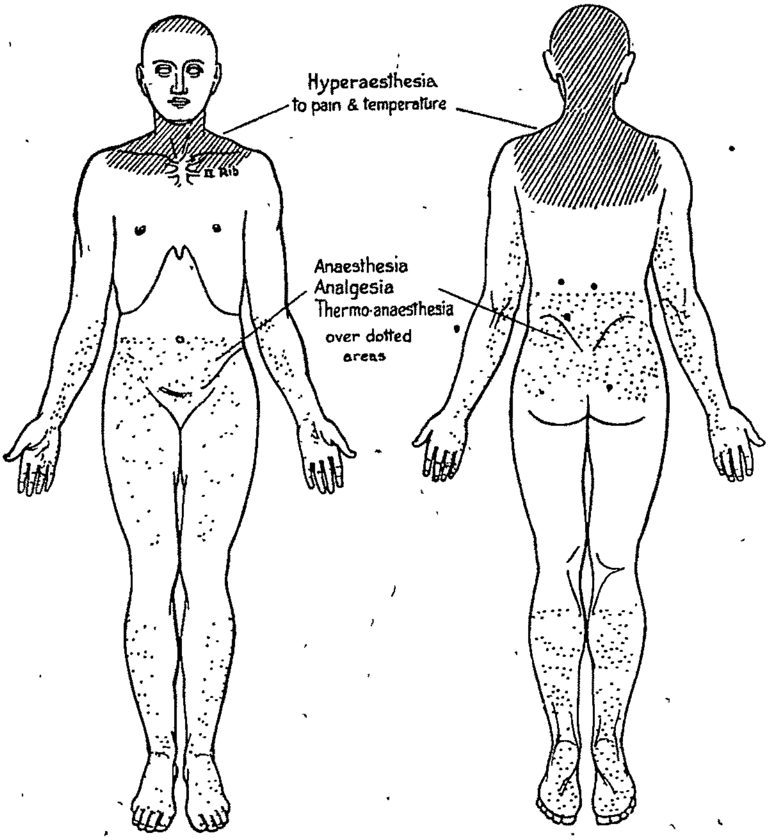

FIG. 1.

On March 15 her condition was as follows: The pulse was 40, hard and regular, the temperature normal; and respiration 20. She was unable to stand or walk, paralysis of the legs being almost complete. She was able to grasp things with the hands, and had fair power of movement in the arms. There was some incoördination in both arms and legs, and some loss of the sense of position of the limbs.

She complained of a good deal of pain in the scapular regions, neck, and arms. The main nerve-trunks of the arms, and in the legs the peroneal and posterior tibial nerves, were tender to pressure. The limb-muscles generally were also somewhat tender to pressure. Hyperæsthesia of the skin was present over the suprascapular regions, over the front and back of the neck, and the posterior aspect of the scalp as high as the vertex. Sensation to touch, pain and temperature was lost over the areas supplied by each ulnar nerve and by the musculo-cutaneous and external popliteal in the legs (fig. 1).

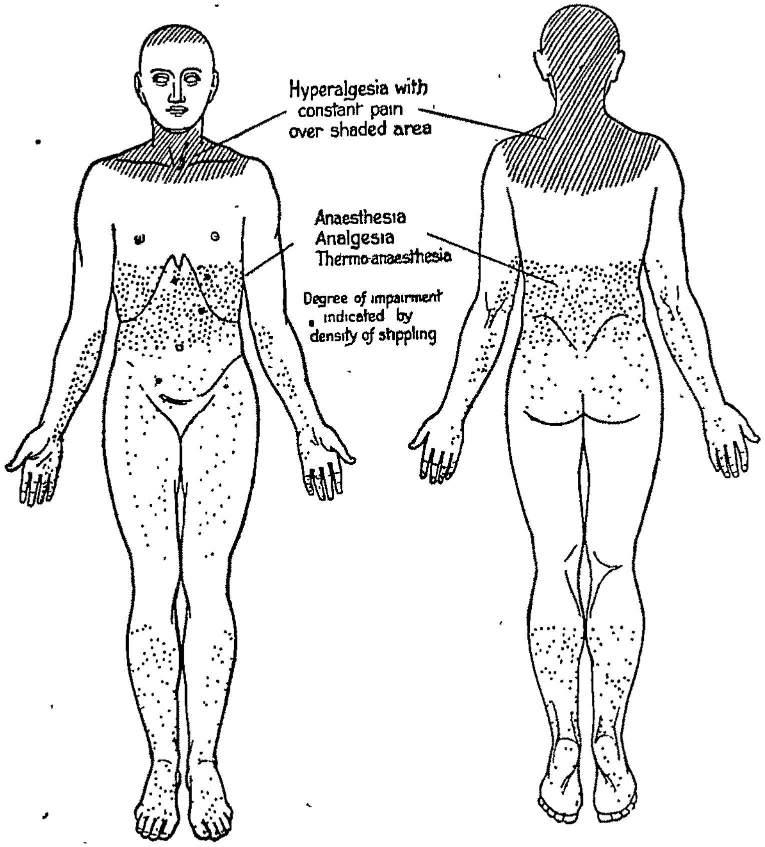
Hyperalgesia with constant pain over shaded area
Anaesthesia
Analgesia
Thermo-anaesthesia
Degree of impairment indicated by density of stippling

FIG. 2.

The knee-jerks were exaggerated; there was no ankle-clonus; the abdominal reflexes were present, the plantar absent.

The patient's condition remained much the same for some weeks. But some wasting of the thenar and hypothenar eminences in each hand, and to a less degree of the interossei, made its appearance. She complained of a persistent sweet taste in the mouth, neuralgic pains in the cheeks and about the orbits, and a sense of oppression in breathing, due to partial or complete paralysis of the diaphragm; coldness of hands and feet appeared, with great irregularity of the pulse-rate, which varied many beats within a few minutes.

On May 10 the motor paralysis was unaltered. Figs. 1 and 2 show the disturbance of sensation at this date and on May 21. Some incoördination in both arms and legs was observed. The reflexes remained as before. The muscles were generally soft and flaccid, except those of legs, which showed slight spasticity.

Reaction of degeneration was present in the wasted muscles of thenar and hypothenar eminences; elsewhere some diminution of excitability to faradic current.

We may mention here that the temperature was normal or subnormal throughout, and the urine contained no albumen.

No further change occurred in the condition until June 14, when profound nausea with a persistent sweet taste in the mouth came on. There was no sugar in the urine or saliva. The tongue was clean and moist. The nausea and loathing of food became so extreme that she finally refused absolutely to take any nourishment, and had to be fed by enemata. The nausea was accompanied by three or four attacks of vomiting daily, quite irrespective of taking food, and not controlled by the various drugs tried.

Until June 23 she suffered much from pain and tenderness in the neck, which prevented her from moving her head. After this date the cervical pains disappeared, and with them the hyperalgesia of the occipital and nuchal regions. On June 28 retention of urine appeared for the first time, and on this day she also complained of oppression in breathing and the respiratory rate fell to 16, whilst the pulse-rate, which for some time had been at 60, rose to 85, but remained regular. On June 29 the respiration fell from 16 to 12, and on one occasion to 6 per minute, and with this the pulse went up to 106, the highest pulse-rate being associated with the slowest respiratory rate. On the 30th, respiration 6 to 4 per minute, pulse 160; the temperature, previously subnormal, rose to 99·5° F. On the evening of this day the respiration rose to 30, but at 9.30 p.m. fell to 6 and then to 2, when she died, with a full, regular pulse of 120, the cause of death being evidently respiratory failure.

Dr. Mackay obtained leave with great difficulty to examine the brain and cervical spine, but all further examination was positively refused. The brain appeared healthy in all parts. As to the cord, to the naked eye there was marked congestion of the dura mater on its posterior aspect, and it was swollen at the level of the third and also at the sixth and seventh cervical nerves. The vessels of the pia-arachnoid were congested, intensely so on the posterior aspect, beginning above at the sixth cervical, and increasing in intensity to the third dorsal roots. The posterior roots themselves appeared reddened, the anterior perhaps slightly so. On incising the cord a few minute red points and streaks were seen, more especially in the posterior root-zone on either side, from the seventh cervical to the third dorsal levels, and the cord was softened at the level of the eighth cervical and first dorsal segments. After three to four days in 4 per cent. formalin the pons, medulla, and cord were transferred to the various fluids necessary for the following stains: sections were cut in close series and stained by Marchi's and Busch's methods, Weigert, Nissl, and van Gieson stains, hæmatoxylin, rubin and rosin, and by a general stain for micro-organisms.

It may be said at once that Marchi's and Busch's methods gave negative results and that no micro-organisms were seen. Sections stained by Weigert's method also showed that the white matter of the cord was healthy and that the fine plexus of nerve fibrils in the grey matter was almost everywhere intact. In a few places, however, where the vascular changes described below were most marked, the fine fibrils were deficient in number. The vascular changes were very conspicuous by this stain, and in some of the perivascular channels there were fat droplets.

By the remaining methods the chief changes found were (1) intense congestion and dilatation of vessels. In the upper part of the cervical cord, as low as the sixth or seventh cervical roots, this affected almost entirely the anterior spinal artery and its branches; below this the posterior spinal arteries were equally affected; the injected vessels showed, from the number of leucocytes they contained, that there was a well-marked leucocytosis going on; (2) escape of red blood-cells into the perivascular channels; (3) microscopic hæmorrhages with a little (never great) destruction of grey matter in their immediate periphery; (4) extensive proliferation of epithelium of central canal.

The injected vessels were most conspicuous in the cervical cord at the inner side of the base of the anterior cornu, and often also at the base of the posterior. The dilated vessels were either themselves so distended as to render inconspicuous the perivascular sheaths, or the latter contained red blood-cells; the capillaries and minute arteries from these dilated blood-vessels could be easily traced through the grey matter; they were greatly distended, the sections often looking like an injected specimen of the cord. In some of the minute arterioles and veins there was noticed swelling and proliferation of the lining endothelium, and in some places a similar appearance in the cells lining the perivascular space. There were one or two microscopic hæmorrhages into the tip of anterior horn at the level of the second and third cervical roots. As low as the fifth cervical the grey matter was unaltered, and, except for excessive pigmentation in places, the anterior horn-cells were normal, even in the immediate contiguity of the most striking vascular changes. From the fifth to eighth cervical segments the vascular changes were even more pronounced, and here a small number of the anterior horn-cells had suffered, showing mostly the first degree of change by Nissl's method; a very few were altogether degenerated. These injured cells were always in the immediate neighbourhood of the most marked vascular affection, and belonged to the anterior mesial, antero-lateral and posterior lateral groups respectively at different levels, and the whole number affected was but small; in fact, a striking point was the integrity of the nerve-cells and grey matter generally side by side with the great vascular congestion. On the whole, the grey matter was most damaged at the base of the anterior horn around the group of large branches of the anterior spinal arteries.

From the first to fourth dorsal segments the pia mater on the dorsal surface of the cord, unaffected above this level, was swollen, its vessels injected, and there was inflammatory exudation into it. The vessels entering with the posterior roots and their capillary branches were enormously distended, and contained a very large number of leucocytes; many capillaries were apparently thrombosed; the grey matter of the posterior horn was swollen and had a homogeneous appearance. Here the anterior horns were little affected, but below this again, so far as available material reached, they showed well-marked changes.

Similar appearances were found in the medulla. At the lower part of the decussation of the pyramids the left tubercle of Rolando was deeply injected, the capillaries filled with leucocytes, a very few of which were passing into the surrounding grey matter, which in places appeared granular, and stained badly.

At the level of the tip of the calamus scriptorius, and for a short distance above it, the vessels lying just below the dorsal surface and supplying the vago-accessorial nucleus were intensely injected, even the smallest capillaries standing out clearly; in some the red cells had escaped into the perivascular space. Ventralwards, an enormously distended vein was seen in the position of the nucleus ambiguus. In all these vessels there was evidence of a marked leucocytosis. The cells of these nuclei, however, seemed intact and healthy. At the upper end of the hypoglossal nucleus a microscopic hæmorrhage had occurred in a small part of its dorsal area; the capillaries here were full of leucocytes and contained hyaline thrombi; the rest of the nucleus, constituting about two-thirds of the whole, appeared intact. The respiratory bundle, "slender column," and nerve-roots were healthy.

Above the level of the sixth nucleus, close to the raphé and just below the grey matter of the fourth ventricle, was another small hæmorrhage, and around it the capillaries were distended and full of white cells; the vessels on each side of the raphé were distended in most sections. The vessels in the pia mater on the ventral surface of the pons were injected, and in the pons itself those about the central grey matter and raphé also appeared congested, but no hæmorrhages were found.

The cells of the various nuclei, the reticular formation, and the longitudinal and transverse fibres of the pons and upper part of the medulla were normal.

In spite of the great injection of the vessels and the number of leucocytes, there was no evidence, except in one slight and unimportant instance, of any invasion of the surrounding nerve tissue, either grey or white matter, by leucocytes.

Even allowing for the variations in the appearance of the central canal in normal cords, as regards its patency and the number of cells of epithelial type which surround it, the changes in this case call for some remark.

In the upper dorsal cord the normal ring of columnar epithelium was intact, the canal was of normal size, and in it could be counted in different sections from six to as many as thirteen lymphocytes. The epithelium was proliferating at its base, so that the canal was surrounded by several rows of these proliferated cells which were passing into the tissue of the commissure. Above this the canal was more or less obliterated throughout, and in the greater part of the cervical region its place was occupied by a rounded or oval mass of cells, obviously derived from the lining epithelium. These cells had a fairly abundant protoplasm, staining lightly and diffusely, the outline or border of the cell being difficult to distinguish and containing a clearly defined large oval nucleus with an abundant chromatin network of the type of the nucleus of an epithelial cell. This change affected the canal right up through the medulla until it opened out into the fourth ventricle. Where it was most advanced the original line of epithelium was undistinguishable, but where this epithelium remained it could be plainly seen that the proliferated cells originated at its base and passed off to invade the surrounding tissue, often for a considerable distance.

Finally, both anterior and posterior nerve root fibres appeared healthy at all levels and contained no degenerated fibres. As it has been mentioned that the vessels contained many leucocytes, and the patient was at the time of onset engaged in nursing a case of acute lymphatic leukæmia, it may be well to mention that there was no suggestion of this disease in the present case.

Some of the pathological changes found explain fairly some of the symptoms present; thus the slowing of the pulse and respiration, both early in the illness and again towards its close, would be accounted for by recurrent microscopic hæmorrhages in the region of the vago-accessorial nucleus. The persistent nausea and vomiting would also attend a lesion of this nucleus, and possibly the persistent and nauseating sweet taste, of which the patient so greatly complained, might have its origin in the medullary lesion. Even here, however, the integrity of the cells of the nucleus indicated that there was no absolute destruction of it, and that the disturbance was a functional one. The pains around the chest, the early loss of sensation on the ulnar side of the forearms, and the paræsthesia felt here may be referred to the great injection of the posterior roots, the inflammation of the dorsal pia mater, and the swelling of the grey matter of the posterior horns in the cord, beginning at the level of the eighth cervical and extending to the fourth dorsal roots.

The other pathological changes in the cord, however, consisted, with the exception of a very few microscopic hæmorrhages and also of a few altered nerve-cells (showing chromatolysis, with very few exceptions, in an early and recoverable form), merely of intense vascular congestion. Although the affected vessels were those that supply the grey matter, this showed slight alteration, and only in a few places. It had apparently sustained no extensive or widely spread damage. A striking feature was the way in which the grey matter often appeared healthy, both in its cells and fibres, and by different methods of staining, in the immediate neighbourhood of the most marked vascular congestion.

The white matter appeared uniformly healthy.

It is in respect of the slight extent of the pathological lesions when compared with the severity of the clinical symptoms, and especially the completeness of the paralysis, that the case seems worthy of record, in spite of the fact that the whole cord could not be obtained for examination. This was most unfortunate, but from the onset of symptoms in the arms, neck and chest; and the subsequent paralysis of the arms, it may be fairly inferred that the changes in the lower part of the cord were of the same nature. The case also in no way corresponded to one of peripheral neuritis. The suddenness of onset at once suggested a vascular lesion, either thrombosis or hæmorrhage.

It is conceivable that in a case in which, following an intense microbic or toxic infection of the cord, a rapidly spreading paralysis is followed by death after a certain number of hours; *e.g.*, in the most acute forms of ascending spinal paralysis, no striking changes should be found in the cord, even by modern histological methods, but that in one where the paralysis was so marked and lasted for nearly twelve weeks so few indications of disease should be found was contrary to all expectation.

So far as can be judged from the character of the lesions, they were due to the action of the poison, possibly infective; unfortunately there is no further evidence of its nature. The changes in the central canal, the grouping of the lesions around it, and their greater intensity in its neighbourhood, are suggestive that, whatever the nature of the poison, it obtained access to the central canal, and thence proceeded to affect the cord. There is good evidence that the central canal is in connexion with the lymphatic system of the cord; it may have been infected by this route. The observations of Schlegel [1] on an infective myelitis (meningomyelitis hæmorrhagica) in horses are important in this connexion. This affection Schlegel found to be due to a streptococcus, and its course is much more acute than in our case, mostly ending fatally within some days, but the lesions he describes are very similar. They affected especially the pia mater and the grey matter of the cord, and in the latter were situated around the central canal, extending thence towards the periphery, and consisted of injection and dilatation of vessels, extravasations around them, and hæmorrhages.

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RECENT WORK ON APHASIA.

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DURING the past three years disorders of speech resulting from esions of the brain have been the field for much work and of much valuable controversy. At the commencement of this period the subject was surrounded by many difficulties. Ideas of the physiological mechanism of speech had been built up through deductions from the clinical aspects and pathological findings in cases of focal disease of the brain in which the pathological examination had been, almost without exception, incomplete; such cases are therefore relatively inconclusive in the light of our present knowledge of the methods of examination essential in local cerebral lesions to an accurate localization of function. Often authors have reasoned from the external examination of the surface of the brain only, and, indeed, Broca's original observations and his original theory were founded upon such superficial examination. The majority of observers have relied upon the examination of the surface of the brain and serial macroscopic sections; and since it is impossible by the latter method to distinguish the living from the dead tissue with any degree of accuracy, it follows that deductions based upon this method of examination are also inconclusive. No worker had set up the standard of serial microscopic sections throughout the brain as the essential basis of the localization of the lesion in cases of aphasia. One of the results of the recent controversy has been the exclusion, as inconclusive, of all cases in which the localization has not been arrived at by this method.

The many schemes with their accompanying diagrams of the localization and interconnexions of the speech-centres, that have been brought forward by high authorities upon this subject, have been founded more upon theory than upon trustworthy pathological evidence; upon these schemes classifications of the clinical varieties of aphasias have been based, which from the first have been open to the criticism that varieties of aphasia were included and described which were purely hypothetical, and which had not been met with clinically. These were types of aphasia which should have resulted from lesions in certain situations, had the scheme which gave them birth been a correct representation of the physiological mechanism of speech. The multiplicity and complicity of the schemes and diagrams that have been brought forward are in themselves a proof of the difficulties that have arisen in the attempt to apply them to clinical cases. In many instances cases which have during life shown speech-defects corresponding exactly with a lesion in a certain position according to a particular scheme have, upon pathological examination, shown that the lesion, either in position or extent, was entirely incompatible with the correctness of the scheme. The very cases upon which a new scheme has been built up have proved, years after, upon pathological examination, the undoing of the scheme which had been based upon them. No hypothesis had been raised which was not thrown into doubt by some clinical variety or other.

The very foundations of our ideas of the speech-mechanism, the registration of the elements of speech as "visual word-memories," "auditory word-memories," and "kinæsthetic word-memories," were of necessity purely conjectural, however well they may have served as a working hypothesis. The generally accepted ideas of the localization of the speech-functions in the cerebral cortex were open to just criticism. The localization of the "visual word-centre" postulated by Wernicke in 1876, and placed by Dejerine in the angular gyrus, has received but little support from facts, though perhaps not negatived by them, and it was still a theoretical centre. Lichtheim's "ideational speech-centre" has been abandoned even by its author as a separate centre.

The recognition of the fact that the focal lesions which are productive of the aphasias are never strictly limited to the cortex, that when involving the cortex they are at once both cortical and subcortical, and generally much more subcortical than cortical, has introduced a further difficulty in the localization of these centres, inasmuch as the subcortical portion of the so-called "cortical lesion" may by isolation render functionless regions of the cortex not directly involved in the lesion and apparently healthy.

The localization of the chief speech-centre in the left temporal lobe was proved beyond doubt, but the existence of an "auditory word-centre" in the posterior half of the second temporal gyrus was not proved, the best evidence of such a localization being the case reported by Dejerine [14], in which, as a result of chronic polioencephalitis, the cortex alone of this region was destroyed, the second temporal convolution being chiefly affected; the clinical picture was that of word-deafness.

At the epoch under consideration the state of opinion as to Broca's localization of the motor speech-centre in the left third frontal gyrus may be gathered from the writings of Dejerine and of his pupil Bernheim, both ardent supporters of Broca's localization.

Dejerine [16], while assured that this centre occupies the "cap" and "foot" of the third frontal gyrus, thought that it extended also to neighbouring gyri, very probably to the second frontal gyrus and to the frontal operculum, possibly, but improbably, to the anterior convolution of the insula. Bernheim [6] was forced to admit that there was not one case on record which had been examined by recent methods and which proved beyond all doubt the truth of this localization.

The distinction between the clinical varieties of aphasia is not always a matter of simplicity. In the recent controversy this fact has been well exemplified, since the same cases have been claimed by one author as instances of "motor" aphasia and by another author as instances of "sensory" aphasia. As this possibility of confusion between the so-called motor and sensory types of aphasia has an important bearing upon the issue dealt with in this paper, it is necessary here to define certain of these types and to point out where confusion may arise. Concerning the types "pure motor aphasia" and "pure word-blindness" there is neither difficulty nor dispute. "Pure motor aphasia" results from a subcortical lesion isolating the speech-centres upon the outgoing side, and its clinical features are loss of or difficulties with spoken language, with the complete conservation of internal language and intelligence, articulation remaining natural. "Pure word-blindness," the type of Dejerine, results from a subcortical lesion which isolates upon the incoming side the speech-centres from the primary visual centres in either hemisphere, its characteristics being inability to appreciate written language, with complete preservation of internal speech, outgoing speech and intelligence. It is to the "pure motor aphasia," as above defined, that Marie applies the term "anarthria," a term that has been used by all previous writers as signifying defects of articulation only.

The "motor aphasia of Broca's type" may be defined as loss or disturbance of spoken language, with some interference with internal speech, and associated almost invariably with alexia, agraphia, and with intellectual defects, these associates varying much in degree and in persistence. A lesion of the "cap" and "foot" of the left third frontal convolution was held responsible for this variety of aphasia.

The "sensory aphasia" of Wernicke resulted from a lesion involving the posterior two-thirds of the left second temporal gyrus and perhaps also of surrounding gyri. This type was characterized by conspicuous defects of internal speech and of intelligence, by complete or partial inability to comprehend spoken and written language, and consequent on the destruction of this, the chief speech-centre, severe defects of outgoing speech, paraphasia and jargon-aphasia were often present.

A comparison between these two types of cortical aphasia, the "motor aphasia of Broca" and the "sensory aphasia of Wernicke," shows at once that the difference between them is rather one of degree than of kind, and may not therefore be an essential difference, since the aphasia of Broca involves troubles on the sensory side, alexia and amnesia, and the aphasia of Wernicke involves troubles with outgoing speech. That the troubles upon the sensory side in Broca's aphasia are usually slight in degree and transient does not necessarily make an essential difference between the two forms, and while there can be no confusion between well-defined cases of the two types, every gradation from the one type to the other is met with clinically. The question has therefore arisen, "Is the separation of the so-called 'cortical' aphasias into 'motor' and 'sensory' types a just one?" and "Is the difference between them determined by a different localization of the lesion, or by the different degree of damage to function caused by lesions in more or less the same position?"

Westphal, in 1884, drew attention to the fact that cases of Broca's aphasia present some of the characteristics of Wernicke's aphasia, and many authors since that time have emphasized this fact. Von Monakow [8], writing in 1905, states that the distinction between these types is often a matter of the greatest difficulty, and since he has formally admitted the existence of paraphasia in the clinical picture of Broca's aphasia he has removed another factor for the distinction of the two forms. It is argued also against Bastian and Wyllie that in their writings they have repeatedly confused the two types both clinically and pathologically. In the recent controversy this same argument has been hurled from both sides at the opposition.

The type to which the term "total aphasia" ("type Broca-Wernicke," "type mixte") is applied results from lesion in both Wernicke's and Broca's regions, and it comprises severe defects of intelligence and of all the elements of speech. In this connexion it is very necessary to point out that in deducing localization from cases where there have been multiple lesions involving the speech-centres, one of which exceeds the others greatly in magnitude, it has been almost invariably the custom of writers to attribute the speech-defects to the larger lesion, to the neglect of the smaller lesions. The recorded cases of aphasia in which recovery has occurred after extensive lesions, and those in which the aphasia resulting from small lesions has remained permanent, make the fallacy of such deductions obvious; and further, the extent of a lesion small to the unaided eye can only be correctly determined by the microscopic examinations of serial sections. For example, many cases have been used as cases of pure Broca's aphasia without hesitation by eminent authorities in which small lesions have admittedly existed in Wernicke's zone.

The above considerations will give the reader some idea of the necessity for the reconsideration of the whole subject of aphasia which Pierre Marie demanded in 1906. The whole subject was complicated, confused, and too much beset with schemes and diagrams. There was no working hypothesis that was universally and easily applicable to the clinical varieties of aphasia; no classification of the clinical varieties that did not entail confusion. The very foundations of the subject were necessarily hypothetical, the ideas of the registration of speech-memories in separate centres of the cerebral cortex admitted of reconsideration, while the pathological basis of the subject demanded fresh data obtained by incontrovertible methods of research.

Pierre Marie's [44] attitude is that of a destroyer and reformer. His desire is to sweep away the majority of previously existing ideas and theories upon the subject of aphasia. He challenges the conjecture that speech-memories are registered in the cerebral cortex as "visual word"-memories, "auditory word"-memories, and "kinæsthetic word"-memories. He denies the existence of a visual word-centre, and indeed of any centre for visual speech situated in the angular gyrus or supramarginal convolution. He denies the narrow localization of Wernicke's centre in the posterior two-thirds of the left second temporal convolution. He denies that the left third frontal gyrus has any function whatever in connexion with the speech-mechanism. He admits of no distinction between the so-called "motor" and "sensory" cortical aphasias, and he rejects these terms as being unwarrantable and useless. He argues that there is only one speech-centre diffusely localized in the left temporo-parietal lobe, that this centre is a region of intelligence specialized for language, not a centre of sensory images ("Une zone intellectuelle spécialisée, pas un centre sensoriel d'images"). The so-called "word-blindness" and "word-deafness" are defects of the special intelligence of speech, and are not due to the loss of function in centres in which sensory images of words are represented. He contends that there is but one variety of aphasia from a lesion of the cerebral cortex, and that this corresponds with the aphasia of Wernicke which results from destruction of the region of intelligence specialized for language and situated in Wernicke's zone; and that, according to the degree of depression of function produced by the lesion, the special functions of the region are lost in the reverse order of their depth of impression. This aphasia must be sharply distinguished from the conditions having their origin in subcortical lesions—namely, "anarthria" and "pure alexia." The classical aphasia of Broca is a combination of aphasia with anarthria, and is the result of a double lesion, the one situated in the region of Wernicke, determining the aphasia, and the second lesion within a quadrilateral area around the lenticular nucleus determining the anarthria. The limits of the quadrilateral region, a lesion of which is productive of anarthria, are, anteriorly and posteriorly, vertical frontal planes level with the anterior and posterior limiting sulci of the insula respectively. Its outer limit is the surface of the insula, its inner limit the wall of the lateral ventricle. Above this the quadrilateral is prolonged towards the overlying gyri of the convexity, while below it is lost in the subthalamic region. The lesions productive of anarthria are usually situated in the upper two-thirds of this quadrilateral. The quadrilateral is in connexion with the third frontal convolution in front, but contains no part of the latter, whilst behind it is in connexion with Wernicke's zone by means of the temporo-parietal isthmus, a compact band of white matter rounding the posterior marginal sulcus of the insula. Lesions situated in front of this isthmus are productive of anarthria; those situated behind the isthmus are productive of aphasia.

These views of Marie have given rise to much criticism and controversy. Dejerine [14-18] came forward as the champion of the older ideas, and with his school has fought hard, especially for the retention of the left third frontal convolution as the motor speech-centre. This controversy has given birth to much excellent literature upon the subject, among which stand out the delightful monographs of Dejerine for his side, and of François Moutier [61] as the exponent of Marie's views.

On the one hand, certain critics have advised the rejection without hesitation or further consideration of Marie's doctrine. Among these are Mahaim [42], Debray [13], and Van der Hoeven [61], and a perusal of their comments gives the impression that these are both hasty and without a sound basis. On the other hand, certain authorities have accepted entirely Marie's doctrine, notably Dercum [20], Collins [61], Lasalle-Archambault [33], Dieulafoy [21], and others of the French school. Dercum has recently declared that he has never found Marie's doctrine at fault in practical application. Between these extremes the majority of those who have criticized Marie's position admit the necessity for the revision of the subject, and most of them, while inclining to the conception of the chief speech-centre as a centre of intellect specialized for language, seem unwilling to exclude Broca's area as an unessential part of the mechanism of speech. But within the last few years evidence has been accumulating from another aspect of cerebral function which has the most important bearing upon the interpretation of speech-defects and which is opposed to a part of Marie's doctrine. Liepmann [35] in 1900 brought into prominent notice a state of inability to perform skilled movements with the limbs in the absence of paralysis, loss of coördination, sensory loss or gross intellectual defect. This condition of apraxia has been worked at by many observers since Liepmann, and a review of the subject by S. A. K. Wilson [78] has recently appeared in *Brain*. The term "apraxia" is here confined to the motor apraxia of the classifications, and in the writer's opinion it should always be so confined. The evidence at present available suggests very strongly that apraxia is dependent upon a lesion situated in the region of the first and second frontal convolutions of the left side. That is to say, that the ability to perform certain subjectively purposive movements or movement-complexes on either side of the body is dependent upon the integrity of the posterior parts of the first and second frontal convolutions of the left side. There is reason, too, for thinking that the connexion of these centres with the left side of the body is by means of the anterior fibres of the corpus callosum and the opposite hemisphere, since a localized subcortical lesion involving the callosal fibres from the posterior extremities of the first two frontal gyri on the left side has been associated with left hemiapraxia as the sole symptom. The bearing of this evidence upon the localization of a motor speech-centre in the left third frontal convolution is obvious and striking, for motor aphasia bears the same relation to movements of the muscles concerned in speech as does apraxia to the movements of the limbs. Motor aphasia, pure or cortical, is clearly synonymous with apraxia, pure or cortical, of the movements concerned in speech, and motor agraphia is apraxia pure and simple. According to this view a series of higher motor centres concerned with certain subjectively purposive movements are situated in the posterior parts of the three frontal gyri and immediately in front of the Rolandic centres (lower motor centres) for the corresponding regions of the body. Lesion of these centres is productive of phenomena of a similar order in the corresponding region of the body—namely, motor aphasia, motor agraphia and apraxia.

At a time, then, when the most determined efforts are being made, and upon grounds which are at least logical, to dismiss the left third frontal gyrus from our conception of the essential speech-mechanism, evidence of a very strong nature is increasingly coming to hand which calls for the retention of Broca's area as a speech-centre, entirely apart from the consideration of local lesions of the brain causing speech-defect. We shall see later on that there is other important evidence which forbids us to accept at the present time the doctrine of Marie in so far as the left third frontal gyrus is concerned. In the writer's opinion it is this part of Marie's scheme that is the weakest. Against this part of his contention alone have substantial arguments been brought, and around it has the controversy waged most hotly.

The writings of von Monakow [59] upon this subject of "diaschisis" are important in connexion with this question. He would make an absolute distinction between those defects of speech which are only seen soon after a lesion has occurred, which are slight in degree and which soon pass off, and those which are well marked and permanent. The early and transitory symptoms he explains by a lowering of functional activity in a more or less distant part of the speech-mechanism, due to the upsetting of balance between the several parts of this mechanism produced by the destruction of one of the integral parts by the lesion. This phenomenon he calls "diaschisis." It must not be forgotten that the nervous system acts as a whole, and not in terms of its individual elements. Similarly the speech-mechanism acts as a whole, and not in terms of its hypothetical centres. For example, von Monakow would explain the slight and transient alexia which so commonly occurs in cases of Broca's aphasia as the result of damage to the speech-mechanism as a whole, causing lowering of function and temporary loss of the least impressed function—namely, visual speech. Marie [44] takes an opposite view, insisting with truth that the alexia, agraphia and amnesia occurring in cases which have been claimed and used as classical cases of Broca's type have been of considerable degree and often not transient. Every gradation from this to Wernicke's type occurs, and for Marie such symptoms are proof-positive of the existence of lesions of Wernicke's zone which he insists are always present in cases of Broca's aphasia. In connexion with another part of the subject, however, Marie seems to make use of von Monakow's explanation when he says that alexia is best explained by a lowering of function in the general centres of vision.

The theory of Bernheim, of Nancy [3], put forward in 1907 as a general conception of the whole subject of aphasia, stands alone and widely apart both from the older hypotheses and from the doctrines of Marie. This theory recalls the ancient hypothesis of Bouillard, who assumed that the prefrontal lobes of both hemispheres were the all-important centres for speech. Space does not admit of the discussion of this peculiar theory, the principles of which are as follows: All aphasias are subcortical in origin and result from lesions of transmission paths. The brain, as the organ of thought, produces internal speech. There are no centres for auditory word-memories nor for visual word-memories: cortical sensory centres for primary perception of impressions alone exist. The memory-images are called up in the psychic sphere (frontal lobe), as are all the phenomena of consciousness. There are no kinæsthetic centres for articulation or for writing. The coördination of movements for articulation and for writing occurs in the nuclei of the medulla and of the cervical region of the spinal cord respectively, which have become automatically associated by habit. Broca's aphasia may be the result of the severance of the prefrontal projection. "In reality," he says, "Broca's aphasia has not been localized, for the good reason that it is not localizable." It is important to notice in connexion with Bernheim's theory that he is the only writer who has laid stress upon the possibility of isolation of the prefrontal region from its connexions accounting for the phenomena of defective intelligence, &c., which are shown by cases of Broca's aphasia. It appears to the writer of the present article that this possibly important point has not been sufficiently considered by authors in connexion with the symptomatology of lesions of the left third frontal gyrus and of the posterior parts of the other frontal gyri.

Following this brief survey of the question as it stands at present, it is necessary to consider in greater detail the chief points in Marie's doctrine, with the arguments for and against, and to discover whether it is possible at the present time to arrive at legitimate conclusions concerning his chief contentions. Whilst considering this subject it is important to keep certain anatomical facts in view. The lesions chiefly concerned in the production of aphasia are vascular in origin, and as such rarely, if ever, are strictly limited to, and involve the whole of, a region of which the functional localization is attempted. Again, vascular disease is a general disease affecting many of the cerebral arteries, and its result is, in most cases, multiple lesions; isolated lesions rarely. There is hardly a case in the whole records of the subject against which these arguments cannot be raised: "the lesion extended beyond the region in question," or "other lesions were present in other regions," and therefore the cases are inconclusive and arguments cannot be logically based upon them. Such cases, which form the bulk of the literature of aphasia, though individually inconclusive, are collectively of such weight as cannot be lightly disregarded.

The term "cortical lesion," as applied to the local lesions productive of aphasia, means a lesion of the convolution as a whole, and the limit of a cortical lesion is a line drawn tangential to the deepest grey matter of the sulcus bordering the convolution; everything deep to this line is subcortical. It has already been pointed out that lesions reaching the surface of the brain are almost always both cortical and subcortical, and usually much more subcortical than cortical.

THE QUESTION OF THE LEFT THIRD FRONTAL CONVOLUTION.

Destruction of a limited area of the brain does not always produce the usual symptoms, and these may be completely absent. For example, cases are on record in which wide destruction of the Rolandic gyri, of the Rolandic projection, and of the internal capsule occurred, and in which there was no hemiplegia. However inadequate the theory of transference and of "gaucherie" may be, and however inexplicable the occurrence is, yet the fact remains that such events do occur in rare instances, and they do not absolutely prove that the region destroyed has not the function usually attributed to it. It must be admitted, however, that an unusual number of cases in which the left third frontal convolution has been destroyed, without the appearance of aphasia, have been recorded, considering the rarity of similar occurrences in other regions of the brain.

The grounds upon which Marie bases his exclusion of the left third frontal gyrus from the essential speech-mechanism are (1) that the collective evidence of all the cases which have been reported in the literature of the subject is strongly against the hitherto accepted theory of a motor centre for speech in Broca's region; (2) that in his own very wide experience he has never seen a case which, on careful examination, supported this view; and (3) he has another explanation and localization for the "motor" speech-defect.

The collective evidence of the literature is remarkable, and is summarized thus by Moutier [61]: Between the years 1861 and 1906, 304 cases with autopsy have been published bearing upon this subject. Of these cases 201 are not really of value, since in twenty-six cases the clinical or the pathological records were so incomplete as to give the reader no conviction as to the nature of the case, and in the remaining 175 cases the lesions were too vast for accurate localization.

There remain, then, 108 cases in which the lesions were localized, and the records sufficient for purposes of argument. In nineteen only of these cases did the facts appear to support Broca's theory, and in eleven of these the lesion was confined to the subcortex; in eight only was the cortex of the left third frontal gyrus affected.

The remaining eighty-four cases were entirely against the classical theory; in fifty-seven the left third frontal gyrus was intact, and motor aphasia was present. In twenty-seven cases this convolution was destroyed and there was no aphasia present, and in two of the latter cases the left third frontal gyrus was destroyed upon both sides.

According to Moutier, a careful examination of the nineteen apparently favourable cases shows that even these cases are the reverse of conclusive; in some there were multiple lesions, in one there was an extensive lesion of the right temporal lobe. Complete alexia was present, and there is no mention as to whether the patient was left-handed or not. He sums up the analysis with the words "there does not exist in medical literature one observation of Broca's aphasia in which a single lesion, strictly localized to the foot of the left third frontal gyrus, has been proved to exist upon autopsy."

This evidence would seem to be overwhelming in favour of Marie's doctrine; but it is to be remembered that it is the summary and conclusion of a worker convinced of the truth of the new doctrine, and who gives no quarter to possibly fallacious cases that stand against him. He has, however, excluded no case without logical and detailed reasons.

It is interesting in this connexion to refer to the analysis of 104 cases of aphasia, with autopsy made by Frankel and Onuf in 1899. They met with four cases only which seemed to confirm Broca's localization, but they examined five cases of Broca's aphasia in which the left third frontal convolution was absolutely intact, and in which the afferent and efferent fibres connected therewith showed no traces of degeneration.

Two cases of Burckhardt's [11] are peculiar in the literature, and are worthy of note. In the one case this surgeon removed 5 gm. of the grey matter from the foot of the first and of the second left temporal gyri, no word-deafness resulting. Eight months later he resected the cap and foot of the left third frontal gyrus, and no aphasia resulted. In the second case, Burckhardt removed part of the left supra-marginal gyrus; subsequently he performed two destructive operations upon Wernicke's zone, and finally resected the cap of the left third frontal gyrus. At no period did this patient present any speech-defect. These patients were dements, and the operations were undertaken with the idea of relieving verbal hallucinations and logorrhœa.

The fact that an observer so eminent and of so wide experience as Pierre Marie states without reserve that no case has come under his personal observation which confirms the localization of a motor speech-centre in the left third frontal gyrus is in itself of great weight, and it necessitates a careful reconsideration of opinions and the recording of fresh observations, with the exclusion of every possible fallacy on the part of all workers upon this subject. Marie was by no means the first to call the classical localization in question. Twenty years ago Allen Starr [76] found it impossible to come to any determination upon the localization of Broca's centre, since no one in America had observed a case with a strictly localized lesion. From this time onwards many authors have drawn attention to the poverty of the evidence for this localization, though none has formally opposed it. Authorities upon cerebral surgery seem to be in universal accord in regarding Broca's aphasia as a most untrustworthy localizing sign.

The localization of the "motor" phenomena of Broca's aphasia or of "anarthria" in a new region, that of the quadrilateral, is admittedly the weakest part of Marie's argument. He is unable to express a definite opinion as to which are the essential structures in the quadrilateral, of which disturbance gives rise to "anarthria;" nor does he attempt any physiological explanation. And further, it has been proved beyond doubt by Madame Dejerine that the projection-fibres from the cap and foot of the third frontal convolution enter the quadrilateral, and are contained in that part of the quadrilateral, lesion of which most frequently produces "anarthria." Madame Dejerine [19] further shows that a lesion of the quadrilateral opposite the upper end of, or above the anterior convolution of the insula, must isolate the third frontal gyrus by section of its projection-fibres, and also that the foot of the corona radiata enters the quadrilateral. The question of the quadrilateral and its localization will be discussed in detail later.

Dejerine [16], who leads the opposition against the doctrines of Marie, commences his argument in the following words: "It is at the present time undeniable that it is difficult to defend with anatomical proofs the localization of articulate speech strictly and uniquely in the posterior third of the third frontal convolution. This localization is possible, but it has not been proved beyond doubt. But though future researches may necessitate the extension of the localization of articulate speech to parts immediately neighbouring upon the foot of the third frontal gyrus, one thing is certain, and it is that there is in this zone a region, a lesion of which determines motor aphasia, and it does so in the absence of any alteration of the temporal lobe." He then puts forward two new cases which he has investigated by the method of serial microscopic sections. In the one case the lesion involved the anterior two-thirds of Broca's convolution, the orbital part, the cap and to a slight extent the foot of the convolution being affected. It implicated the underlying white substance of F3 and F2 and the foot of the anterior segment of the corona radiata. It involved slightly the cortex of the anterior marginal sulcus of the insula and the anterior fifth of the external capsule. The clinical aspect in this case was typical of Broca's aphasia. Most of the speech-defects had disappeared six months after the occurrence of the lesion, and this recovery Dejerine attributes to the relative escape of the foot of the third frontal convolution.

In the second case the lesion occupied the cap of F3 and the adjacent portion of F2. The "quadrilateral" and Wernicke's region were intact. Lesions, however, were present in the right hemisphere: (1) In the paracentral region, (2) in the middle portion of the first limbic gyrus, (3) in the second frontal gyrus, and (4) in the knee of the corpus callosum. The clinical aspect of this case was again typical of Broca's aphasia, and the condition remained permanent.

Dejerine considers that these cases are conclusive of the presence of a motor speech-centre in the region of F3. Marie contends that the first case was one of temporary anarthria from lesion of the anterior part of the quadrilateral (the anterior gyrus of insula and anterior fifth of the external capsule were involved). In his experience, cases of true Broca's aphasia never recover as did this case. To the second case he objects on the ground of multiple lesions involving general defect of intelligence. Against both cases he urges that he has never seen a case of true Broca's aphasia without accompanying hemiplegia.

Dejerine points out that in all cases which have been brought forward by Marie [47], Moutier [51-55], Souques [71-75] and others of this school, as cases of Broca's aphasia from combined lesion of Wernicke's zone and of the quadrilateral, the degree of word-blindness and of word-deafness that has been present has been so great as is only met with in cases of sensory aphasia or total aphasia, and that from the severity of word-blindness and word-deafness present their cases must be excluded as arguments bearing upon the classical aphasia of Broca. Every case that these authors have cited in which there has been no lesion of the left third frontal gyrus with motor aphasia and in which lesions have been present in Wernicke's zone and in the quadrilateral, according to Dejerine are cases either of sensory aphasia from the lesion of Wernicke's zone, or cases of total aphasia from an additional destruction of the projection and connexions of the left third frontal gyrus which are contained in the anterior and upper part of the quadrilateral.

Dejerine [16] explains the cases in which Broca's convolution has been destroyed and in which no aphasia has been present on the ground of possible dominance of the right hemisphere, ambidexterity, compensation by surrounding regions and compensation by the right hemisphere.

Von Monakow [60] firmly supports the classical localization of Broca, and in conjunction with Ladame [30] has recently published an important case confirming his opinion.

A careful and open-minded consideration of the evidence and arguments that have been brought forward upon both sides of this question and of the evidence gathered from recent studies upon apraxia leave us with a firm conviction in favour of the retention of the left third frontal gyrus as an important speech-centre upon the outgoing side.

For the motor speech-centre it is a question of choice between Broca's centre, our conceptions of which are at least intelligible, and an unlocalized and functionally unexplained motor mechanism situated somewhere in the vast area of the quadrilateral. And since the quadrilateral has been proved beyond doubt to contain the projection of F3 and also the foot of the anterior part of the corona radiata, it may be that the "anarthria" ascribed to the lesion of the quadrilateral results in reality from section of the projection and connexions of the cap and foot of the third frontal gyrus.

THE QUESTION OF THE "QUADRILATERAL" AND OF "ANARTHRIA."

It matters not that Marie uses the term "anarthria" in a different sense to that in which it has been hitherto employed, for his definition of it is clear and involves no confusion. It means "loss of, or difficulties with, articulate speech, with complete preservation of internal speech and with the absence of articulatory troubles of a paralytic nature." It is identical then with Broca's "aphemia" and with "pure" or "subcortical" motor aphasia. He uses the term "dysarthria" for articulatory troubles of a paralytic nature. It is, however, difficult to follow Marie when he suggests that anarthria may be the result of a lesion of the quadrilateral in either hemisphere, and that a lesion of the quadrilaterals of both hemispheres is productive of dysarthria (pseudobulbar paralysis); for the latter is surely dependent exclusively upon bilateral lesion of Rolandic centres and their projection-fibres.

The quadrilateral of Marie is a vast region taking up a good proportion of the middle third of the hemisphere. It is bounded externally by the surface of the insula, and internally by the lateral wall of the third ventricle. In front and behind it is bounded by vertical frontal planes at the anterior and posterior limits of the insula respectively. Below it merges into the subthalamic region, and above it is limited by the convolutions of the convexity. It is connected with Wernicke's zone by the temporo-parietal isthmus, the two making up the only localizable speech-region. Lesions of this region behind the isthmus are associated with aphasia, lesions in front of the isthmus with anarthria.

It seems clear that the limits of the quadrilateral laid down by Marie [44] are rather for purposes of forming a convenient working plan in the unsatisfactory state of our knowledge concerning the functions of this region, than to insist upon a dogmatic localization. The argument, therefore, that has been brought against him that his localization is no localization at all seems to be beside the point, for he candidly admits that he is unable to point out which are the essential structures in the quadrilateral lesion of which produces anarthria, and he is unwilling, moreover, to set up any hypothesis as to the function of many of the structures contained in the quadrilateral, nor will he theorize as to the way in which anarthria is produced.

It is quite beside the question to ask Marie (as has been frequently done in the recent controversy) whether he thinks that anarthria can be produced by a lesion of the optic radiation, of the thalamus, of the caudate nucleus and of the internal capsule, though all these structures are contained in the quadrilateral. The real question is concerned with the functions of the cortex of the insula, of the extreme capsule and claustrum, of the external capsule, of the projection of F3 and the foot of the corona radiata, in so much as these occupy the quadrilateral, and of the corpus striatum.

Concerning the function of the insular cortex, extreme capsule and claustrum, little is known. Some authorities who hold by Broca's localization would extend the motor speech-centre on to the anterior gyrus of the insula. The external capsule contains the forward connexions of Wernicke's zone, and if Broca's localization be correct it must contain the connecting path between Wernicke's centre and Broca's centre, and a lesion of it therefore must entail anarthria by separation of the two centres. A lesion of the anterior and upper part of the quadrilateral would be likely to involve the projection-fibres of the third frontal convolution and the foot of the corona radiata, and the resulting anarthria is easily explicable, according to Broca's theory, as pure motor aphasia from isolation of the third frontal gyrus from its downward path.

There remains to be considered, then, the corpus striatum, and to the importance of this structure in the production of anarthria Marie commits himself. He says: "I should say that the lenticulo-striate body represents, either by itself or with its afferent and efferent paths, a mechanism far more important from a motor point of view than does the left third frontal convolution in the production of speech."

Now it is well known that the anatomical connexions of the lenticulo-striate body are with the thalamus, and with Luys' nucleus, that it sends no fibres into the cerebral peduncle, and that it has little or no connexion by fibres to the cerebral cortex directly. The cortical projection-system, though many of its fibres traverse the corpus striatum, sends no fibres which end in, or connect with, the corpus striatum. From these facts the lenticulo-striate as a motor mechanism for one of the highest cerebral functions—that of speech—is in the highest degree improbable.

There are no clinical and pathological records which give any support to the theory that the lenticulo-striate body is intimately concerned with the speech-mechanism, and the same may be said, though less confidently, of the cortex of the insula and the immediately underlying structures—the extreme capsule and the claustrum.

The very arguments that Marie has used against Broca's localization and the supposed function of the left third frontal convolution are applicable, and with greater force, against his localization in the quadrilateral and against the presumed function of those structures in the quadrilateral which possibly may be concerned in the speech-mechanism. It must be remembered that Marie has not committed himself to any localization of speech-function within the quadrilateral beyond the reference to the lenticulo-striate body given above, nor does he define the lesion within the quadrilateral productive of anarthria more definitely than by stating that it is most common in the upper two-thirds of this region.

Our conclusion must be that Marie has not proved his case for the shifting of the motor speech-function from Broca's region to the quadrilateral, yet the question is one that needs much further investigation before a satisfactory solution can be arrived at.

IS THE SO-CALLED BROCA'S APHASIA IN REALITY WERNICKE'S APHASIA (WORD-BLINDNESS AND WORD-DEAFNESS) PLUS ANARTHRIA?

Accepting Marie's definition of anarthria and placing the lesion responsible for this in the region of or beneath the left third frontal convolution, it seems quite clear that Marie is correct in claiming the presence of the double lesion in a great many of the cases that have been included as cases of Broca's aphasia. Dejerine's contention that Marie's cases are examples of total aphasia is identically the same proposition as is Marie's argument that Dejerine's cases are cases of aphasia plus anarthria. The more severe degrees of word-blindness and word-deafness occurring in cases of Broca's aphasia are much more easily explicable, and do not require the stretch of imagination if we accept Marie's teaching that they are the result of a second lesion in Wernicke's zone, than is necessary when we revert to diaschisis and general depression of the speech-functions to aid our conceptions.

It remains for subsequent investigators to show how far a lesion limited to Broca's region is associated with word-blindness and word-deafness. Dejerine [16] admits it to his conception of the results of a lesion of the left third frontal gyrus in slight degree and as a transitory symptom only. Marie [44] excludes it altogether from his definition of anarthria. Recorded cases show every degree, both of severity and permanence, and they give no means of clinical distinction between cases claimed as examples of Broca's aphasia and of Wernicke's aphasia respectively. If we admit a cortical motor centre for speech, forming an integral part of the physiological basis of internal speech, from our knowledge that the majority of individuals are strong "visuals" as regards general intelligence, and strong "auditives" as regards the special intelligence of speech, even allowing for individual variation and different degrees of education, we can only attribute a very minor importance to the motor speech-centre in internal speech. Therefore we can only admit of slight and transient disturbances, either of intelligence or of receptive speech, as the result of the upset of balance and lowering of the functional capacity of the speech-mechanism as a whole from the damage to its motor centre, and we must agree with Marie that anything beyond such slight and transient disturbances is strong evidence that Wernicke's zone is also involved.

THE NATURE OF THE SPEECH-FUNCTION OF THE CEREBRAL CORTEX.

By far the most important part of Marie's doctrine is his conception of the speech-function of the cerebral cortex, and in the opinion of the writer of this paper this conception will receive general acceptance as the working hypothesis of the future. He argues with great weight against the hitherto accepted theory that the elements of speech are registered as sensory images—"visual word" images, "auditory word" images and "kinæsthetic word" images—in the cerebral cortex. The separation of the visual part of speech from the auditory part of speech is erroneous, while the separate localization of these functions in the cerebral cortex rests upon no foundation in fact whatsoever. The forms of the so-called "transcortical aphasia," that have been supposed to result from lesions isolating these centres, exist in theory only and have never been demonstrated by clinico-anatomical methods. The existence of a separate visual speech-centre and an auditory speech-centre rests upon the slenderest facts, and is controverted by everyday experience. The nervous system does not act in terms of its individual elements, but as a whole. The individual elements of the speech-region of the brain have no isolated function; consequently there can be no mapping out of the localization of isolated parts of the speech-function in the cerebral cortex. The speech-function is diffusely localized as one centre in the left temporo-parietal region, and this centre is an intellectual centre specialized for speech, not a sensory centre for the storing of sensory images. Destruction of some of the individual elements of this centre is productive not of loss of isolated parts of the speech-function, but of a general depression of speech-intelligence and of general intelligence which results in the loss of the speech-functions, in reverse order of their depth of impression, according to the severity of the destruction in the speech-region. For example, a foreign language is lost first, and most by the aphasic, and is regained last and least. The visual speech-function, being less deeply impressed than the auditory speech-function, is much more affected by a slight lesion than is the latter.

The whole of the phenomena of aphasia are much more easily explained on the ground of varying degrees of crippling of a single speech intelligence centre than upon the old hypotheses.

The consideration of the phenomena of aphasia as defects of intelligence is a very old idea, and it was held by Trousseau. It has never been eradicated from current ideas on the subject, as the introduction of ideational centres into many of the "schemes" of the speech-functions shows. It has been held by Marie for many years, and his experience has convicted him of its truth. At the present time many authorities accept this view. Grasset [25] accepts it, von Monakow [40] inclines to it, and Dieulafoy [21], in the fifteenth edition of his "Manuel de Pathologie Interne," has adopted the entire doctrine of Marie in his description of aphasia.

The origin of the theory of "sensory" aphasia rests with Wernicke. Following upon the work of Meynert, Wernicke [44] traced what he considered to be the central acoustic path to the region of the first temporal gyrus and the insula. This anatomical discovery led him to theorize the existence of a centre for the comprehension of spoken language in the first temporal gyrus, and by an extraordinary coincidence almost at the same moment he made the clinical discovery of that form of aphasia which has ever since borne his name. Within a short time he was able to examine the brains of two patients with this defect, and in both of them there was a lesion of the left temporo-parietal region. This apparently emphatic confirmation of his idea led Wernicke to put forward his theory of "sensory" aphasia. An anatomical investigation upon a sensory path, a postulated centre for the comprehension of spoken language, a brilliant clinical discovery, and two autopsies founded "sensory" aphasia. This doctrine was universally accepted within a short time, and it was subsequently amplified and extended as the result of reasoning and of psycho-physiological methods of introspection, and not from clinico-anatomical observations. It was thus that the conceptions of separate centres registering separate sensory images, with complicated inter-connections, arose, and from these were deduced in theory the nature of the speech-defects which ought to result from destruction of the various separate parts of this complicated speech mechanism.

The theory of sensory images is contradicted by clinical facts. Let us take, for example, a case of partial word-deafness. The patient is able to comprehend perfectly, and to respond to simple sentences and commands. Make these sentences and commands more and more complicated, and a point will be reached when he neither understands nor responds. Put these same complicated sentences and commands to him in a dissociated form as a series of simple phrases and orders, and he again understands perfectly and obeys. Here there is obviously no loss of auditory word-memories, for he understands perfectly when the sentences and commands are simple. But he does not comprehend when the same commands are mixed together. This is obviously due to a lowering of the function of the speech-centre as a whole, and not to the loss of one of its parts endowed with a specific and localized function. Tests of this nature can be applied to every part of the speech-function with the same result—that of controverting the theory of sensory images.

The vocabulary in aphasia, both upon the receptive and upon the outgoing side, shows no gap compatible with the destruction of regions in which definite word-memories are registered. Such patients retain words in the order of the depth with which they are impressed and the extent to which they are used subconsciously.

If we abandon the theory of sensory images, and accept Marie's conception of a single centre of intellect specialized for language, situated, broadly speaking, in the region of the angular gyrus, supra-marginal gyrus, and the posterior parts of the two upper temporal gyri of the left side, a multitude of the phenomena presented by patients with aphasia become easily intelligible, which were inexplicable or admitted only of highly forced explanations upon the old theory. The absence of a single recorded case of isolated cortical alexia, previously explained on the grounds that the visual word-centre and the auditory word-centre were so close together that a lesion of the former necessarily involved the latter, is now explained by the non-existence of a separate visual word-centre. The constant association of alexia with word-deafness and its persistence over the word-deafness when partial recovery occurs, which is really inexplicable by the old theory, is a strict consequence of the new theory; for the visual speech-function of the single centre is a less impressed function than the auditory speech-function, and is therefore the first to be lost and the last to be regained when the speech-centre is damaged. Again, the patient whose voluntary speech is reduced to the production of two or three words only, and who, when started either with the voice or by accompanying music, can sing a song of many verses with perfect articulation, is absolutely contradictory to the theory of sensory images. Such a case is a proof that the images are not lost, but that the speech-function as a whole is depressed, yet can be temporarily roused into a condition of higher activity by the emotional elements of sound and rhythm. Did space permit, it would be easy to put forward many phenomena occurring in these patients which can only be adequately explained by the new theory, but the above are sufficient in this place.

Anatomical proofs, either of the separate existence of a "visual word-" and an "auditory word"-centre, or of the local registration of sensory images in the speech-centre, or, indeed, of any functional localization in the general speech-centre, may be said to be absolutely wanting if the single case of Dejerine, already referred to, be excepted.

It is many years since Dejerine [8] suggested the localization of a visual word-centre in the angular gyrus, and there has been no anatomical confirmation of his idea, and there have been many records which disprove it. It may, with justice, be said that narrow localization within the speech-area by the combination of clinical and anatomical methods is impossible from the nature of the lesions which we have to interpret, since these are vascular lesions, and as such are both cortical and subcortical, and generally much more subcortical than cortical. The subcortical part of the lesion isolates much more of the cortex of the speech-centre than the lesion appears to involve. For this reason we must discount, to a certain extent, the value of recorded cases of local lesions in the speech-centre (second temporal gyrus).

Strict and narrow localization of function in the cerebral cortex is, in all probability, an erroneous idea. Perhaps it is relatively true as regards the cuneus, and, to a less extent, as regards the Rolandic cortex. In the cuneus there is strictly local representation of the visual field as regards the quadrants, but while an extensive lesion of the region representing the quadrant produces a complete quadrantic hemianopia, a small lesion does not cause complete loss of part of the quadrant, but produces a partial loss over the whole of the quadrant. That is to say, each quadrant is represented as a whole, and partial damage impairs the function of the quadrant as a whole. The absence of strict localization in the Rolandic region was pointed out by Hughlings Jackson many years ago in his description of "representation in compound proportion." The paralysis that results from a local lesion of the motor cortex is never a strict monoplegia, but it is in reality a partial hemiplegia.

Marie and Guillain [50], in their work upon the pyramidal tract, pointed out, in antagonism to existing beliefs, that the result of small local lesions in the motor region of the internal capsule was not the production of various monoplegias as was usually taught, but the production of a widely-spread hemiplegia of slight intensity, and the larger the lesion the greater was the intensity of the hemiplegia. Marie deduces from this fact a law which he would extend to the whole of the cerebral cortex. He says: "This law of the production of cerebral hemisyndromes from a lesion of a small portion only of the region which gives rise to such syndromes is applicable throughout the brain. It is thus that a local lesion of that region of the brain which has to do with the perception of common sensation is productive of a hemianæsthesia of all one half of the body. It is thus that a lesion of the cuneus, however small, gives rise always to a hemianopia, and, finally, it is according to this same law that a local lesion of any and of every part of Wernicke's zone gives rise to an aphasia involving every part of the speech-function."

Dejerine is entirely opposed to this "Loi globale" of Marie, and he insists that the nature of the symptoms that result from a local lesion are entirely dependent upon the position of the lesion. In the opinion of the writer of this paper the evidence is strongly upon Marie's side as regards Wernicke's zone and the higher regions of the cerebral cortex, but that at present Dejerine's opinion is justified, so far as the motor centres, and probably also the centres in the posterior parts of frontal gyri, are concerned.

Marie in his doctrine lays great stress upon the intellectual defects shown by patients with aphasia. Aphasia is to him essentially an intellectual defect entailing defects both of the specialized intelligence of speech and of general intelligence in every case. In this opinion he is supported by many eminent authorities, including Grasset and von Monakow. He uses the fact of the presence of marked intellectual defects in all these patients as important evidence of the unvarying presence of a lesion of Wernicke's zone, and as a proof of the unity of aphasia. Cases of aphasia in which intelligence has been said to be perfect have been brought forward by the supporters of Broca's localization, but Marie clearly shows that in these cases the evidence of complete intellectual capacity is quite inadequate, since not even the simplest tests were applied. He has been able to prove beyond doubt the presence of obvious reduction of intelligence among all those under his care. He points out their inability to tell the time by the clock and to put the hands of the clock at a given hour, and their ineptitude for the simplest mathematical calculations. He instances the common experience of the aphasic musician who is unable to play the music that he formerly knew by heart. He cites the case of a highly skilled cook who became aphasic and who was said to have no defect of intelligence. This man when taken to the kitchen was unable to prepare even the simplest dish. Such defects are not defects of speech-intelligence; they are defects of general intelligence and can be found in every person with aphasia.

The speech-functions of the right hemisphere were held by Bastian to be important, for he considered that speech centres existed in the right hemisphere in similar positions to those of the left hemisphere and with similar function but of lower functional value. Marie is of opinion that Bastian's view has not received sufficient attention. With Moutier he would place a second Wernicke's zone upon the left side, and the function of such a centre as forming part of the general region speech-intelligence and the results of local lesions of this region are readily intelligible upon his doctrine. He states that "anarthria" may result from a lesion of the right quadrilateral in a right-handed person. Marie agrees with the usually accepted ideas regarding compensation and re-education both in surrounding regions and in the opposite hemisphere as explaining the recovery which occurs in aphasia. Such recovery is of slow occurrence. He quite rightly rejects altogether the theory of sudden or rapid transference of the speech-centres as a pure invention which has been made to account for absence of aphasia with a lesion of the left Broca's gyrus in right-handed subjects.

For this same reason he condemns the theory of "gaucherie" in the right-handed person, and he points out the disproportionate number of the cases of lesions of Broca's convolution into which this explanation has been drawn. No such forced explanation, he says, will save Broca's localization. Marie has not recently expressed his opinions as to the bearing of our increasing knowledge of apraxia upon the subject of aphasia, and Moutier, beyond a criticism against the conclusiveness of recorded cases, does not discuss the subject in his monograph. Marie [44] in 1906 explained apraxia as an intellectual defect. He considered that the seat of the lesion responsible for apraxia was somewhere in the speech-region, and that this region was perhaps also a centre for the ideas of highly skilled and conventional acts. From the defect of intelligence produced by the lesion the apraxic patient was unable to perform certain acts. The apraxic subject was, in fact, suffering from aphasia of low intensity. On the one hand the apraxic was unable to understand the command, and on the other hand the idea of the exact nature of the act demanded of him escaped him. At the present time such an explanation as the above is entirely untenable in the light of the cases of apraxia confined to the left side, and without right hemiplegia, that have been reported.

The doctrine of Marie, in so far as his conceptions of the chief speech-centre are concerned, marks a step in advance in our knowledge of the subject of aphasia, and will probably receive general acceptance. It is more in accord with facts, it is less beset with theory, it is a far better working hypothesis, and it is a sounder basis for future research than are the classical theories.

The retention of Broca's localization at the present time seems imperative from the evidence both on the side of aphasia and apraxia, and it is quite compatible with the rest of Marie's doctrine. In forming our opinion we have to choose, according to either doctrine, a motor speech-mechanism subsidiary to the chief speech-centre. We are offered the left third frontal gyrus and the classical ideas of its function by Dejerine. We are shown the quadrilateral by Marie, and we are asked to accept some structure as yet not definitely pointed out within this area. At the same time we are not sure that these alternative localizations are distinct, for it is possible that the same structures are involved in the lesions in either localization which are productive of aphasia.

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A Text-book of Psychiatry for Physicians and Students. By LEONARDO BIANCHI, M.D. Authorized translation from the Italian by JAMES H. MACDONALD, M.B., Ch.B. Glasg. London: Baillière, Tindall and Cox, 1906.

AT a time like the present, when the study of psychiatry is being prosecuted both in Europe and in America with a vigour hitherto unprecedented, the appearance of an English translation of the work of the famous Italian neurologist and psychiatrist should be especially welcome.

The volume, which contains upwards of 900 pages, is admirably translated, and, even in its most abstruse passages, is as intelligible as if it had been originally composed in the English language. The translator, in fact, cannot be too warmly congratulated on the successful performance of an exceptionally difficult task.

That the book is already several years out of date is of little import to English psychiatrists, as its chief value depends on the fact that it contains the reasoned opinions of an eminent representative of the Italian school of psychiatry. It is, however, to be regretted from the aspect of the student that no attempt has been made by the author and the translator to refer to, if not to incorporate, the important results of recent research.

The volume is divided into three parts, which deal respectively with the anatomy and physiology of the cerebrum, the physiopathology of mind, and the subject of mental disease.

The first part calls for little remark. The anatomy of the cerebrum is lucidly described, but the account contains no reference to the important histological researches of the past eight or ten years. The localization of the visual area, for example, dates from the work of Henschen, Vialet, Dejerine, Brissaud, &c.; and the account of the differential structure of the cortex generally from the publications of Hammarberg and Schlapp, and the earlier researches of Cajal and Flechsig. It is therefore hardly necessary to remark that the description of the physiology of the cerebral mantle, which, considering the date at which it was evidently written, is excellent, contains no reference to the experimental work of Sherrington and Grünbaum.

The section on the physiology of language is exceptionally good, and is worthy of careful study. The views of the author as to existence of centres for percepts and even for abstract conceptions, which are distinct from those for the images of words, are clearly expressed and ably discussed. The chief argument adduced in favour of a concept centre is sufficiently expressed in the following sentence: "If, then, the word can be learned and pronounced completely void of conceptive significance, as in the case of infants and idiots, and if it be true that even the dements, when their intelligence is resolved into its elements, can pronounce many words deprived of their signification and devoid of any conceptive content whatsoever, inasmuch as the concepts themselves are resolved into their imaginative elements, many of which have been lost with the destruction of the mind, one can only conclude that the words which clothe the conceptions have a seat of distinct formation, and that whilst in one case the conceptions may disappear and the words remain, in another the latter may disappear and the former remain in a state of latency." It may, however, be remarked that the truth that concepts may disappear and the words remain does not make it necessary to predicate a centre for concepts. It can equally be asserted that words serve merely as symbols on which, with a normally acting cerebrum, it is possible to integrate voluntarily conceptions by complex processes of association, and that a repetition of these processes, similar in fact but different in detail, is necessary whenever an individual conception is evolved. Indeed, it may be argued with regard to both percepts and concepts that just as a percept is symbolized by a word which is meaningless, apart from the arousing of sensory memorial images of various kinds, so a concept is symbolized by a word, but is only integrated by the voluntary performance of still more complex processes of cerebral association.

The first part of the volume concludes with a lengthy criticism of the views of Flechsig, with especial reference to the functions of the anterior and posterior centres of association; and the author repeats and elaborates his well-known views on the functions of the frontal lobes. The following paragraph, which summarizes Bianchi's conception of the functions of the cerebral mantle, is worthy of quotation: "In concluding this first part of the work, one can symbolize the cerebral mantle as a state with a representative system—a parliament and government. The [illegible] parliament would be constituted by the perceptive zones, each of which furnishes to the central government the product of its own labour, accomplished with material prepared by the force of Nature from the primary receptive and ganglionic neurones throughout the course of successive years. The central government would be represented by the frontal lobes, which, utilizing the products elaborated by all the members of parliament, direct in their turn the legislative work to the advantage of the people, who, in the nervous system, are represented by all those millions of neurones, scattered or grouped together in the sensory periphery of the body, in the ganglia, in the spinal medulla, in the posterior, mid and intermediate brain, their products being transmitted to the perceptive centres, which merely transform them and transmit them in their turn to the government, whose synthetic, directive, and regulative influence displays itself in the adaptation of the individual to the new conditions of existence and in the extension of the individual and social environment."

The first chapter of Part II. deals with the physiopathology of perception. The author holds a rather broad view of sensation, defining it as "the notice of the modification induced by external agents (stimulus)." He lays emphasis on the progressive nature of the process of perception, in the sense that it consists "in the perception of differences—that is to say, in the capacity to gather new features and new relations in the external world, as well as to furnish new and useful combinations with the perceptions and the secondary products of these that have accumulated in the mind." It is, however, difficult to see in what way this conception of perception differs from the Continental notion of apperception, and the author evidently finds a difficulty in making the distinction, as he somewhat obscurely defines apperception as "a more acute perception, rendered possible by a more concentrated attention, and promising results of much greater advantage for the evolution of the mind (*vide* the following chapter on attention). It is accordingly the highest expression of the perceptive progressiveness." After a reference to and discussion of the simpler disorders of perception, illusion and hallucination are clearly described and fully illustrated. When considering the question of the source of hallucinations, he supports the hypothesis of Tamburini. "Hallucinations are phenomena whose organic substratum is in every case the respective sensory area of the cortex. The more or less evident alterations that we find there, when we have the opportunity of making sections of the brain of a subject of hallucination, are an indisputable proof of the truth of this doctrine." As an example, he describes in full a case of meningo-cerebral gumma, and remarks: "Such a finding explains all the symptoms; the nodules on the Rolandic zone were the cause of the Jacksonian attacks; the diffusion over all the somæsthetic zone gives the reason of the profound disturbances of kinæsthesis and of the hypochondriacal condition; the diffusion backwards on the occipital lobe and the projection upon the first temporal convolution are to be regarded as the immediate cause of the auditory and visual hallucinations." It may be remarked here, in view of the author's opinions on "sensory insanity," that he applies the term "cortical sensory centres" to almost the whole mantle of the cerebrum behind and below the precentral sulcus, and not simply to the several sensory or projection spheres which are now generally recognized. In other words, Bianchi employs the word "sensory" as the equivalent of "perceptive and sensory."

The next chapter deals lucidly and fully with the subject of attention. "Attention is a psychic fact interposed between perception or its ideative equivalent and the reaction which that tends to provoke." "It is not the will, as some have believed, nor is it apperception. It contributes to the process of apperception and to the direction of the will in the mechanism of conscious reaction." Voluntary and involuntary attention are discussed and the motor phenomena associated with the act of attention are referred to. The author then expresses his views, which are in general agreement with those of Bastian, Ferrier, and Wundt, as to the cerebral seat of attention. "The frontal lobe is the organ of attention, in so far as it is the one on which we bring together the whole intellectual and emotional patrimony of the personality, and in so far as it is the centre for summoning up separate images, of which the equivalents or duplicates are sent from the sensory zones to the frontal lobes for physiological fusion with others and for the formation of mental products of a more elevated order." The chapter concludes with an account of the various disorders of attention.

Memory is next discussed. The author defends his view that concrete images are the products of the combination of elementary images, and that they are conserved in the various perceptive spheres or cortical sensory centres, and not in a special organ of apperception (Wundt) situated in the frontal lobes. When discussing the reproduction of images, after he has distinguished between evocation and reproduction, he describes the former function as voluntary and involuntary, and he concludes that involuntary evocation occurs in each of the respective perceptive (and memorial) spheres. With regard to voluntary evocation he remarks: "Every time, therefore, that a thought arises there comes an order from the frontal lobe to the separate organs that form and conserve the concrete images of objects and of words to bring forward all their products of concrete images for the development of the concept, of which these are elementary components." As, however, the author states that whilst reproduction succeeds evocation, it sometimes arises independently of it, one can only conclude that he wishes it to be inferred that concrete images may arise spontaneously, that they may be evoked by any other local psychic components, and finally, that they may be evoked by the act of volition through the agency of the frontal lobes.

This is not the place for a discussion as to whether Bianchi's views with regard to the existence of definite centres for perceptions and their conservation are correct; but it may be remarked that he gives these centres a location distinct from that of their respective word-images. In this case a word-image could directly evoke its fully developed percept in the respective centre of conservation of this, and would not, as is the opinion of the writer of this review, serve simply as a symbol on which a percept might be integrated from simple sensory memorial images by a complex process of association. Whilst the writer would regard both the concept and the percept as psychological generalizations which indicate different grades of cerebral association, Bianchi appears to consider them distinct entities with cerebral centres of conservation, distinct from the regions which serve as the physical bases of word-images.

The chapter concludes with a lengthy and interesting description of the various disorders of memory.

A chapter on ideation follows. This contains an interesting account of the evolution of language and of the laws of association. It may be remarked, with regard to the author's views on this subject, that he includes under the anatomical substratum of thought—(1) centres for the conservation of elementary images and of concrete images (percepts) which occupy the "sensory areas of the cerebral mantle"; (2) the region of central government and the centre for concepts, which occupy the frontal lobes, and (3) all the zone of language.

Disorders of thought are then referred to, and "deliria" (delusions) are elaborately discussed, classified and illustrated. The chapter ends with a short account, under the doubtfully well-chosen title of "mental confusion," of such symptoms as dyslogia, incoherence, echolalia, coprolalia, &c.

The second part of the volume concludes with chapters on the emotions and sentiments, the will and consciousness.

The different theories with regard to the emotions are discussed at great length, and the author strongly supports the view that emotion is a psychic phenomenon accompanied by, but distinct from, the various somatic phenomena which constitute its physical expression. The will, on the other hand, is rapidly dismissed. It is "nothing more than the conscious resolution of the motor tendencies of the intellectual emotional syntheses, and we may figure it to ourselves as a conscious motor potential tending to discharge itself through circuits of various orders from the lowest, which much resemble the inferior and instinctive reflexes, to the highest, which are represented in the actions of the heroes of humanity." Consciousness is defined as "the *ego* differentiated from the world," and is divided into the illuminated and the non-illuminated, or "the unconscious." The author considers that consciousness has its anatomical substratum in the whole cerebral mantle, but its chief centre in the frontal lobes.

Part III., which deals with the subject of mental disease, occupies the remaining 500 pages of the volume.

The first chapter contains an extremely full and lucid description of methods of clinical examination. The classification of mental affections is then considered, and the various possible bases of classification are critically discussed. The author divides mental affections into three great groups: (1) Those represented essentially by evolutionary psycho-cerebral defect; (2) all the affections of infective, autotoxic and toxic origin developing in individuals regularly evolved; and (3) all the affections with an organic substratum, localized or diffuse, in the central organ of mind.

Whilst the author does not consider the groups to be necessarily mutually exclusive, *e.g.*, the incompletely evolved may be subject to the disorders of the second group, it is quite clear that he really intends the mental affections of the second group to be regarded as of infective, autotoxic or toxic origin.

As regards the question of dementia, he remarks: "All the mental affections of the second group and many of the first, after a long duration, and when they do not recover, give rise to phenomena characteristic of mental decadence, which frequently is slowly progressive." A short description of secondary dementia is inserted as an appendix to the account of the second group.

In group I. are included phrenasthenias (*i.e.*, idiocy and imbecility), paraphrenias (*i.e.*, eccentricity), delinquency (*i.e.*, criminality), epileptic insanity, hysterical insanity, paranoia, fixed ideas and obsessions, neurasthenia, and sexual psychopathies. The description of this group occupies 240 pages, or nearly one-half of the section on mental diseases.

The subject of idiocy and imbecility is treated solely from the aspect of general symptomatology, though the author accepts groups of non-epileptic and non-paralytic, epileptic and paralytic (and choreic), and myxœdematous cases respectively, and gives a short separate description of cretinism. The clinical account is good, but the anatomico-pathological portion is less satisfactory.

A short but interesting chapter on eccentricity is followed by a more lengthy one on delinquency. The author divides delinquents into four classes—moral imbeciles, born criminals, occasional and passional delinquents, and cases of criminal or moral insanity. The first class he includes under the phrenasthenias, and the third and fourth are referred to in the succeeding chapters on the first group of mental affections. The description of the second class is very good, but does not call for remark.

The account of epileptic insanity is interesting, but the chief detail gathered from its perusal is the general resemblance which exists between the descriptions of the epileptic and of the criminal.

An excellent chapter on hysterical insanity follows. It contains a number of interesting cases. The author sums up his conception of hysterical insanity in the remark: "I would say that the hysterical subject has an infantile mind, but sexually is adult and anomalous."

The chapter on paranoia is one of the best in the volume. The author defines this psychosis as "constituted essentially of a disturbance that is mainly intellectual, and through which the personality undergoes a slow transformation in its relations with the outside world.' His views will perhaps be most clearly expressed in his own words: "It is certain that when a man accepts as a reality a false product of his own thought, the very fact of his doing so compels us to admit that there is a great anomaly in the formative process of thought and a serious defect of judgment; the mechanism of thought is subjugated by the emotions and the sentiments that are morbidly predominant. The abnormal emotive state, for reasons that are quite individual, either alters the process of synthesis in the formation of thought, so that the delirium appears to be primary, and not assisted, at least in the beginning by sensory disorders, or it alters the perceptive process, giving rise to illusions and hallucinations, and through the abnormal products of the perceptive sphere deliria are formed." . . . "In all the better known and better studied forms of paranoia the emotions are the fundamental and primary fact." . . . "Paranoic deliria are therefore not autochthonous ideas, but of emotional origin." . . . "These three emotions—suspicion, ambition, and love—give the three classic forms of paranoia: the persecutory, the ambitious or proud, and the erotic." The descriptions of the several types, and also the examples which are given, are excellent; and the psychoses excluded from the group of primary paranoias are mentioned, namely, systematized deliria consequent on other psychoses, all states of confusion and hallucination, and secondary paranoia. It will thus be seen that the author's conception of paranoia accords more with that of foreign than with that of English alienists. In describing this psychosis under mental affections due to cerebral subevolution, Bianchi differs from the majority of alienists, as does the writer of this review. It may be remarked that amongst the types of paranoia are included such forms as religious paranoia, paranoia erotica, and mania for litigation, which the writer regards as symptomatological varieties, due to the special mental configuration of the subjects, rather than as distinct kinds of paranoia. The number of such types might, in fact, be increased almost indefinitely, although all in general symptomatology conform to a standard description.

The chapter on fixed ideas and obsessions is clear and well written, and is followed by a short account of neurasthenia. The latter is defined as "a particular state of the nervous system in which the nervous energy, under whatever form it be displayed, is below the normal minimum relatively to each individual, and below the average of the race to which he belongs," and the author locates it, as regards its physical basis, in the somæsthetic zone of the cortex. The description of the first group concludes with an account of the anomalies of the sexual instinct.

The second group "comprises all the mental affections of infective, autotoxic, and toxic origin developing in individuals regularly evolved." It includes mania, melancholia, maniacal-depressive insanity, sensory insanity, mental confusion, acute and late paranoias, neurasthenic, choreic and luetic insanities, acute delirium, and pellagrous, alcoholic, morphinic, cocainic, chloralic and saturnine insanities. Such critical remarks as appear desirable will be inserted under the several headings.

The author limits the term "mania" to the simple form. As would therefore be expected, he remarks that it is rare, occurring in his experience to the extent of 2—3 per cent. of admissions, and is more common in women than in men. He describes it as mild, typical and grave. He excludes hallucinations from the symptomatology. The description is excellent, but it is difficult to understand why this psychosis is included under the second rather than under the first group.

The description of "melancholia" agrees generally with that of Kraepelin, and in spite of its position in his classification the author does not adduce any new reasons against its being the most common type of presenile involution of the cerebrum.

"Maniacal-depressive insanity" is dismissed in less than three pages, one of which is occupied by excellent diagrams of periodic mania, periodic melancholia, and the various mixed and "circular" types of recurrent insanity. The author states: "We have nothing to add to the pathology of this form, except that it is rooted in grave psychopathic heredity and in anomalies of the character. The prognosis is grave; mental enfeeblement follows much more slowly than in the pure form." As was remarked in the case of "mania," it is difficult to understand why this general type is placed in the second rather than in the first group.

The chapter on "sensory insanity" requires more lengthy consideration. The term "sensory insanity" is defined as follows: "Under this name are included all those psychopathic states which begin with hallucinations and illusions, no matter whether these sensory disturbances dominate the scene during the whole course of the disease or disappear at the beginning of it, leaving syndromes which it would be a mistake to consider as particular forms of disease, since, in point of fact, they form, with the sensory disturbances, one single whole, clinically and psychologically inseparable." The word sensory, as employed by the author, covers both the sensory and the perceptive centres, which approximately occupy, in his opinion, the somæsthetic area (as described prior to recent researches) and nearly the whole of the cerebral cortex behind and below it. "The almost constant fact" in sensory insanity "is the hallucinatory explosion of the disease. . . ." "In the classification I have separated mental confusion from sensory insanity because, in some cases of the former, in retracing the history of the disease, I have not succeeded in satisfying myself as to the hallucinatory beginning."

The author divides sensory insanity into three classes:—

(1) "Illusional or perceptive insanity." This consists "in an illusory perception of one's own physical person or that of others." It is difficult, from the examples cited, to see why these cases are not included under fixed ideas and obsessions.

(2) "Subjects of hallucination of good mental constitution, in whom the hallucinations, being neither intense nor terrifying, but varied, may be repeated for a very long time without disturbing their mental organization and conscious personality." The cases cited would be described by many as examples of delusional insanity, with vivid and varied hallucinations of a persecutory nature.

(3) This includes such syndromes as acute dementia, amentia (Meynert), stupidity, and dementia præcox. The author considers that whatever form mental confusion in such cases may assume, hallucinations, incoherence and deliria (delusions) occur; and, further, that the hallucinations are the cause of the incoherence and deliria.

In the single page devoted to mental confusion the author states that he does not feel warranted in absolutely denying that this may sometimes occur without being preceded by hallucinations and illusions, and this is apparently the reason why it is separately mentioned. It may be presumed that "polyneuritic psychosis" is included by Bianchi under sensory insanity and primary mental confusion, though this is not explicitly stated; whether or not, it is not included, either by name or symptomatology, under "alcoholic insanity."

Space does not permit of any detailed criticism of the author's conception of "sensory insanity," and isolated remarks on it would readily convey an erroneous impression. It may, however, be noted that no satisfactory etiological or pathological basis is presented by the author for the grouping under one heading of such entirely separate types as recoverable intoxication confusions, premature and mature dementias, and the like, all of which commonly, but not necessarily, exhibit illusions and hallucinations as part of their early or acute symptomatology, and some of which, at any rate, can hardly be considered to be always of infective, autotoxic, or toxic origin.

The remaining chapters dealing with the second group, the contents of which have already been enumerated, are short and unimportant. The description of this group concludes with a short appendix on secondary dementia.

In the third group "are included all the affections with an organic substratum, localized or diffuse, in the central organ of mind." It contains chapters on dementia paralytica, and on luetic, senile, post-apoplectic, aphasic and traumatic dementias.

The account of dementia paralytica is similar to that commonly given in text-books and calls for little remark. There is no reference to the age at which the disease occurs, and the juvenile form is not even mentioned. The author considers that dementia paralytica may be provoked by a large number of causes, and that "there is no clinical difference between syphilitic, alcoholic and other non-syphilitic paralytics." Whilst Robertson's researches, and even his employment of serotherapy, are mentioned, there is no reference in the chapter to the work of Mott, which omission in itself is sufficient to demonstrate how much the account is out of date.

A short chapter follows on luetic dementia (syphilitic brain disease).

The chapter on senile dementia excludes "the progressive paralyses of the aged and the psychic alterations consequent upon destructive foci," and is practically a description of second childhood.

The account of post-apoplectic dementia contains nothing of note, but that on aphasic dementia (secondary to cerebral lesions) is excellent. Several good cases of lesion of the visual and auditory word-centres are described. The author's views are summarized in the following sentences: "Thought, in so far as it is a product of synthesis and works logically according to the laws of association, does not exist except in the sensible form of language. If language be suppressed, perception and immediate judgments on images are still possible; not so a train of thoughts or an extended synthesis. . . ." "In ordinary dementia the degenerative process, which involves the textural structure of the whole brain, tends to destroy the elementary components of thought. In aphasic dementia, on the other hand, these last exist integrally, but the processes of synthesis are impeded in so far as these result from the psychological fusion of the elementary components of the word."

It will be noted that, in conformity with the author's acceptance of centres of perception apart from words and their cortical centres, he considers perception possible in the absence of language. It is difficult, however, in view of the above quotation, to understand his postulation of a concept centre apart from language. The writer would rather regard both conception and perception as complex processes of cerebral association which occur through the medium of certain words or word groupings, these being symbolic of concepts and percepts which require integration before such words acquire meaning. From this point of view centres for concepts and percepts do not require postulation, except in so far as the various word-centres serve as physical bases for the different symbols through the medium of which concepts and percepts may be integrated from sensory memorial images by processes of cerebral association.

The book concludes with a short chapter on traumatic dementia.

It is unnecessary to express an opinion concerning a volume which in its several parts exhibits its author as respectively a neurologist, a psychologist and a psychiatrist of the first rank. The book requires to be read to be appreciated, and, although the views expressed are widely different from those accepted by non-Italian schools of psychiatry, the erudition, experience and reputation of the author entitle them to both respect and consideration.

J. S. BOLTON.

PUBLICATIONS RECENTLY RECEIVED.

[*Notes on a book under this heading do not preclude a subsequent review.*]

Saggio di Anatomia Segmentale. La Metameria Somatica, Nervosa, Cutanea e Muscolare dei Vertebrati. Memoria di G. VAN RYNBERK. Profusely illustrated. Pp. 318. Roma: Tipographia della R Accademia dei Lincei, 1908.

In this monograph the author treats of segmentation in all its aspects. After an introduction, in which he deals with the subject in general, he passes to the evidences of myomeric, neural and skin segmentation as discovered by direct examination. The third part of the work is devoted to a consideration of the results yielded by the morphological, experimental and clinical methods with regard to the segmentation of the nervous system. Every scheme that has been put forward is reproduced and duly considered. The book is a wonderful record of the work that has been done on many different lines towards the elucidation of the question. It will be of value, even to those who are unfamiliar with Italian, on account of its profuse illustrations.

The Origin of Vertebrates. By WALTER HOLBROOK GASKELL, M.D., F.R.S. Pp. 537. London: Longmans, Green and Co., 1908.

Throughout the last ten years Dr. Gaskell has published a series of papers bearing on his view that the verebrates have arisen from an arthropod ancestor. The whole of this work has been put together in the present volume in a most attractive form. Each chapter deals with the consideration of some definite aspect of the question. Should a reader be unfamiliar with the detailed investigations of any part of the subject, he can nevertheless follow the general thread of the argument with the help of the excellent summary which follows each chapter. The book is written in a fascinating manner, clear, simple and concise. The innumerable original observations are marshalled with such skill that, although the book is pre-eminently one for specialists, the unlearned are carried on from point to point without fatigue. The stress laid on the dominance of the nervous system in the upward path of development makes the work peculiarly attractive to all neurologists.

An Introduction to Social Psychology. By WILLIAM MCDOUGALL, M.A., M.Sc., Wilde Reader in Mental Philosophy in the University of Oxford. Pp. 355. London: Methuen, 1908.

Psychology is the recognized basis of all social sciences. But as ethics, economics, political science, and the philosophy of history were studied before the birth of modern psychology, they are based on a priori dogmas now recognized to be false. In this interesting book the author reviews modern knowledge on primary instincts, emotions, sentiments and volition. The second half of the book is devoted to the consideration of the part played by primary instincts in the life of societies. It is written in an admirable style, and is full of happy suggestions for thought.

The Functional Inertia of Living Matter: a Contribution to the Physiological Theory of Life. By DAVID FRASER HARRIS, M.D., Lecturer on Physiology in the University of St. Andrews. Pp. 136. London: Churchill, 1908.

The author believes that, in addition to excitability, protoplasm possesses the fundamental property of functional inertia. This is expressed in latent periods, insusceptibilities to stimulation and rhythms. It also lies at the bottom of some of the facts of hereditary disposition, maintenance of type and psychic inertia, and is not merely a diminution of affectability, but a positive property of all living matter.

Mind and its Disorders: a Text-book for Students and Practitioners. By W. H. B. STODDART, M.D., F.R.C.S. With many illustrations. Pp. 488. London: H. K. Lewis, 1908.

This book is divided into three parts, devoted to normal psychology, the psychology of the insane, and a detailed consideration of the forms of mental disease. So large a scheme leads to the somewhat superficial treatment of some of the subjects touched on in the more abstract parts of the work, but more than two-thirds of the book are devoted to a useful and practical account of the phenomena of insanity. It will be useful to the general practitioner or to the student preparing for one of the higher examinations.

The Sexual Life of our Time in its Relations to Modern Civilization. By IWAN BLOCH, M.D., translated from the Sixth German Edition by M. EDEN PAUL, M.D. Pp. 790. London: Rebman, 1908.

This book deals with sexual life, normal and abnormal, with the forensic aspect of offences against morality, with sexual education and many other similar questions. It belongs to a series of works of which Forel's "Sexual Question" i, the best known, written apparently for the intelligent layman rather than the specialist. The pathological portion will add nothing to his knowledge of psycopathia sexualis. The frequency with which words and sentences are printed in heavy type is offensive to the eye of the reader.

Transactions of the Ophthalmological Society of the United Kingdom. Vol. 28. Fasc. iii. London: Churchill, 1908.

This number contains three papers by Mr. Nettleship bearing on heredity—senile cataract in husband and wife: conditions of the lenses in their children and grandchildren, lamellar cataract, discoid cataract, and retinitis pigmentosa, affecting different members of the same pedigree; and, lastly, a colour-blind family. The remaining papers have no general interest.

Handbook for Attendants on the Insane. Fifth Edition revised and enlarged. Published by the Authority of the Medico-Psychological Association.

This well-known handbook has been revised and brought up-to-date for the use of attendants in asylums.

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Members of the Neurological Section of the Royal Society of Medicine can obtain the Index of "Brain" for the Volumes I. to XXIII. inclusive, that is, from its commencement to the end of 1900, from Messrs. MACMILLAN & CO., Ltd., St. Martin's Street, London, W.C., at the price of 6s. 6d., post free.

To those who are not members of the Neurological Section of the Royal Society of Medicine the price is 8s. 6d. net, and the volume may be obtained through any bookseller.

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